PB-240 987

CHARACTERIZATION AND TREATMENT OF URBAN LAND RUNOFF

Newton V. Colston, Jr.

North Carolina Water Resources Research Institute

Prepared for:

National Environmental Research Center

December 1974

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-670/2-74-096

2.

PB 240 987

4. TITLE AND SUBTITLE
CHARACTERIZATION AND TREATMENT OF URBAN LAND RUNOFF

5. REPORT DATE
December 1974; Issuing Date

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Newton V. Colston, Jr.

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
University of North Carolina Water Resources Research Institute
124 Riddick Building, North Carolina State University
Raleigh, North Carolina 27607

10. PROGRAM ELEMENT NO.
1BB034/ROAP:21-ATB/TASK:014

11. CONTRACT/GRANT NO.
11030 HJP

12. SPONSORING AGENCY NAME AND ADDRESS
National Environmental Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final - 7/71 to 9/73

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

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In urban drainage basins, investments in upgrading secondary municipal waste treatment plants without concomitant steps to moderate the adverse effects of urban land runoff are questionable in view of the apparent relative impact of urban land runoff on receiving water quality.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Runoff, *Surface drainage, *Water pollution, Flocculants, Waste treatment, *Water quality, Coagulation, Computers	*Urban runoff, *Storm runoff, *Urban drainage, *Stormflow, *Water pollution sources, *Stormwater characterization, Storm water management model	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 170
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE 6.25

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151

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☆ U. S. GOVERNMENT PRINTING OFFICE: 1975-657-591/5343 Region No. 5-11

EPA-670/2-74-096
December 1974

CHARACTERIZATION AND TREATMENT OF URBAN LAND RUNOFF

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U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The objective of the study described herein was evaluation of the relative impact of urban life characteristics on water quality management. It is only by knowing the magnitude of each individual input that the optimum allocation of limited funds can be established.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

ABSTRACT

Urban land runoff from a 1.67 square-mile urban watershed in Durham, North Carolina, was characterized with respect to annual pollutant yield. Regression equations were developed to relate pollutant strength to hydrograph characteristics. Urban land runoff was found to be a significant source of pollution when compared to the raw municipal waste generated within the study area. On an annual basis, the urban runoff yield of COD was equal to 91 percent of the raw sewage yield, the BOD yield was equal to 67 percent, and the urban runoff suspended solids yield was 20 times that contained in raw municipal wastes for the same area. Downstream water quality was judged to be controlled by urban land runoff 20 percent of the time (i.e., the pounds of COD from urban land runoff was approximately 4-1/2 times the pounds of COD from raw sewage).

It is conceivable that critical water quality conditions are not typified by the 10-year, 7-day low flow, but by the period immediately following low-flow periods when rainfall removes accumulated urban filth into the receiving watercourse, greatly increasing the pollutant load while not substantially increasing water quantity. Specific urban land use did not appear to influence the quality of urban land runoff.

The applicability and effectiveness of plain sedimentation and chemical coagulation of urban land runoff was evaluated. Plain sedimentation was found to remove an average of 60 percent of the COD, 77 percent of the suspended solids, and 53 percent of the turbidity. Cationic polyelectrolytes and inorganic coagulants were found to provide significant residual removal increases over plain sedimentation. Alum was judged the best coagulant and produced average removals of COD, suspended solids, and turbidity of 84, 97, and 94 percent, respectively.

The EPA Storm Water Management Model (SWMM) was evaluated with respect to actual conditions as measured in the field. The model was judged to predict peak hydrograph flows and total hydrograph volumes with reasonable accuracy; however, it was not judged effective for predicting pollutant concentrations.

In urban drainage basins, investments in upgrading secondary municipal waste treatment plants without concomitant steps to moderate the adverse effects of urban land runoff are questionable in view of the apparent relative impact of urban land runoff on receiving water quality.

This report was submitted in fulfillment of Project Number 11030 HJP by the North Carolina Water Resources Research Institute under partial sponsorship of the Office of Research and Development, Environmental Protection Agency. Work was completed as of September 1, 1973.

CONTENTS

		Page
Abstract		iv
List of Figures		vii
List of Tables		x
Acknowledgments		xii
Sections		
I	Conclusions	1
II	Recommendations	5
III	Introduction	7
	Project Scope and Objectives	8
IV	Basin Description and Land Use	10
V	Sampling	27
	Hydrologic Data	27
	Automatic Sampler	27
VI	Characterization of Urban Land Runoff	36
	Hydrologic Information	36
	Individual Storm Characterization	36
	Base Flow Characterization	39
	Effect of Land Use on Water Quality	39
	BOD Difficulties	48
	COD Exertion Rate Studies	52
	Representative Sampling	55
	Pollutant Regression Equations	55
	Annual Pollutant Yield	58
	Summary	63
VII	Chemical-Physical Treatment Studies	65
	Introduction	65
	Jar Test Procedure	66
	Coagulants Evaluated	67
	Coagulant Evaluation	68
	Coagulant Aid Evaluation	75
	Coagulant Selection	75

Sections		Page
	Batch Scale Coagulant Evaluation	78
	Sludge Characterization	80
	Summary	86
VIII	Relative Impact of Urban Land Runoff	88
	Introduction	88
	Comparison with Domestic Waste	88
	Relative Impact on Downstream Oxygen Content	90
	Study Area Characteristics	90
	Problem Formulation	90
	Interpretation of Results	96
	Summary	99
IX	Factors Influencing Stormwater Treatment Economics	101
	Introduction	101
	Collection	101
	Treatment	102
	Sludge Disposal	102
	Summary	103
X	Evaluation of EPA Storm Water Management Model	104
	Introduction	104
	The SWMM Model	104
	Program Blocks	105
	General Data Requirements	105
	Application to Third Fork Creek Drainage Basin	106
	SWMM Verification	108
	Evaluation of Predicted Quantities of Runoff	109
	Evaluation of Predicted Quality of Runoff	114
	Summary	115
XI	References	117
XII	Glossary	118
XIII	Appendix	119

FIGURES

No.		Page
1	Third Fork Creek study area location within Durham city limits and North Carolina	10
2	Drainage pattern of Third Fork Creek within Durham, N. C.	11
3-17	Typical land use within basin	14-21
18-27	Typical stream bed of Third Fork Creek	21-26
28	Schematic diagram showing location and relative elevations of USGS gage house and control weir	28
29	Schematic of automatic sampling system	31
30	USGS gage house adjacent to Third Fork Creek	32
31	USGS control weir and staff gage at gaging station	32
32	Box housing submersible pump at sampling station	33
33	Automatic sampler control box	33
34	Stage recorder and digital precipitation recorder inside USGS gage house	34
35	Plexiglass sampling flume	34
36	Modified vacuum sampler	35
37	Pollutant variations with Q and time for Storm No. 20, Date 6/20/72	40
38	Pollutant variations with Q and time for Storm No. 20, Date 6/20/72	41
39	Pollutant variations with Q and time for Storm No. 13, Date 3/16/72	42
40	Pollutant variations with Q and time for Storm No. 13, Date 3/16/72	43
41-42	Typical variations of BOD with dilution	50-51
43	Oxygen exertion curves as determined by BOD and COD uptake	54

FIGURES (continued)

No.		Page
44-46	Pollutant concentrations in mg/l for a typical hydrograph as predicted by adjusted regression equations	60-62
47	Determination of optimum pH and dosage for alum	69
48	Optimum pH and dosage determination for Dow's C-32	70
49	Determination of optimum pH and dosage for Dow's A-21	71
50	Schematic of batch coagulation-sedimentation column	79
51-52	Suspended solids removal as a function of detention time	81-82
53	Suspended solids removal as areal overflow rate for cationic polyelectrolytes	83
54	Suspended solids removal versus areal overflow rate for ferric chloride	84
55	Suspended solids removal versus areal overflow rate for alum with and without coagulant aids	85
56	Watershed selected for oxygen sag studies	91
57	Typical storm for conditions at Third Fork Creek treatment plant	93
58	Effect of channel shape and flow variation on reaeration coefficient	94
59	Effect of channel storage on storm flow downstream	95
60	Effect of stormwater treatment on oxygen sag under storm conditions	98
61	SWMM map of Third Fork Creek system	107
62-65	Modeled versus recorded hydrographs for USGS main gaging station with associated hyetographs	110-112
66-67	Modeled versus recorded hydrographs for Sub-basin N-2 with associated hyetographs	113
68-69	Modeled versus recorded suspended solids concentration at USGS station and N-2 sub-basin for storm of 6/20/72	114-115

FIGURES (continued)

No. **Page**

70 Modeled versus recorded suspended solids concentrations for storm of 10/5/72 at USGS station 116

TABLES

No.		Page
1	Third Fork Creek Land Use Characterization by Sub-basins	13
2	Hydrologic Description of Urban Runoff Events Sampled	37
3	Average and Standard Deviation of Organics in Urban Runoff Events at the Main Gaging Station	38
4	Average and Standard Deviation of Solids in Urban Runoff Events at the Main Gaging Station	44
5	Average and Standard Deviation of Total Phosphorus, Kjeldahl Nitrogen, and Fecal Coliforms in Urban Runoff Events at Main Gaging Station	45
6	Average and Standard Deviation of Metals Concentrations in Urban Runoff Events at the Main Gaging Station	46
7	Average, Range, and Standard Deviation of Pollutant Concentrations for all Storm Samples	47
8	Average Base Flow Pollutant Concentration for Sub-basins and Main Gaging Station	47
9	Average Pollutant Concentrations from Sub-basins During Storm Flows	48
10	Oxygen Uptake Rates (K_1) for Urban Land Runoff	53
11	Comparison of Pollutant Concentrations Adjacent to Waters Surface with Those Obtained by Automatic Sampler	56
12	Equations Describing Urban Runoff Pollutant Flux Near Channel Bottom in Pounds Per Minute for Durham, North Carolina, as a Function of Discharge Rate (CFS) and Time from Storm Start (TFSS) in Hours	57
13	Regression Equations Predicting Pollutant Concentration (mg/l) in Urban Land Runoff in a Natural Channel Corrected to Flow at Mid-depth	59
14	Estimated 1972 Pollutant Yield for Third Fork Creek Drainage Basin in Pounds/Acre/Year	63
15	Individual Jar Test Results at Optimum pH and Dosage	72

TABLES (continued)

No.		Page
16	Individual Jar Test Results for Coagulant Aids	76
17	Coagulant Ranking on Average Residual Removal Efficiency of COD, Suspended Solids, and Turbidity	77
18	Characteristics of Chemical Sludges	86
19	Comparison of Raw Municipal Waste and Urban Runoff on an Annual Basis in Pounds Per Acre Per Year Pollutant Yield	89
20	Total Annual Yield of Pollutants from Municipal and Urban Runoff Wastes in Pounds/Acre During 1972	89
21	Total Yield of Pollutants During Storm Periods from Urban Runoff and Raw Municipal Wastes in Lbs/Acre During 1972	90
22	Results of Oxygen-Sag Computations for Study Watershed	97
23	Storm of 6/20/72 as Predicted by SWMM	108
24	Effect of Varying Integration Period and Hyetograph Interval of Discharges as Predicted in SWMM on the Storm of 6/20/72	109
25	Comparison of Predicted Peak Flows, Total Gutter Flows, and Time of Peaks for the Four Storms Modeled	110
26	Comparison of Predicted Peak Flows, Total Gutter Flows and Time of Peaks for the Storms Modeled at Sub-basin N-2	112
27-62	Appendix - Time Parameters and Analytical Results of Urban Runoff Events Number 1 through 36	120-146
63-68	Appendix - Third Fork Creek Base Flow Observations at USGS Gage House and Sub-basins	147-152
69-73	Appendix - Time Parameters and Analytical Results of Urban Runoff Events Monitored at Sub-basin Discharge Locations	153-157

ACKNOWLEDGMENTS

The support of Professor David H. Howells, Director of the Water Resources Research Institute for the State of North Carolina, is acknowledged with sincere thanks.

The valuable contribution of Mr. Ernest Lyle Lewis in providing dependable and accurate analyses of urban runoff samples is appreciated. The field assistance of Mr. John Ward, Mr. Russell Radford, and Mr. Mike Wallis is gratefully acknowledged. Mr. Parviz Samar, who conducted the evaluation of chemical treatment, contributed significantly to the success of the project. The technical assistance and review of Dr. Rooney Malcom is appreciated.

The support of the project by the Office of Research and Development, Environmental Protection Agency, and the assistance provided by Mr. Anthony Tafuri, the Grant Project Officer, and D. Dean Adrian, Ph.D., is acknowledged with sincere thanks.

SECTION I

CONCLUSIONS

This project had as its goals the (1) characterization of urban land runoff in Durham, North Carolina, (2) evaluation of the applicability of chemical-physical treatment of urban land runoff, (3) evaluation of the EPA Storm Water Management Model, and (4) determination of that point beyond which the cost of an increased degree of municipal waste treatment exceeded the benefits of partial or total treatment of urban land runoff. Whereas the conclusions and findings of this report are based on information obtained in Durham, North Carolina, the results contained herein are believed to represent urban areas of the Piedmont province on the East Coast.

1. The organic concentration in urban land runoff is approximately one-half that for typical raw waste whereas the concentrations of heavy metals and solids are two to fifty times greater in urban land runoff.

AVERAGE, RANGE, AND STANDARD DEVIATION OF POLLUTANT CONCENTRATIONS FOR ALL STORM SAMPLES

Pollutant	Mean mg/1	Standard deviation	Range (mg/1)	
			Low	High
COD	170	135	20	1042
TOC	42	35	5.5	384
Total Solids	1440	1270	194	8620
Volatile Solids	205	124	33	1170
Total Suspended Solids	1223	1213	27	7340
Volatile Suspended Solids	122	100	5	970
Kjeldahl Nitrogen as "N"	.96	1.8	.1	11.6
Total Phosphorus as "P"	.82	1.0	.2	16
Fecal Coliform (#/ml)	230	240	1	2000
Aluminum	16	8.15	6	35.7
Calcium	4.8	5.6	1.1	31
Cobalt	.16	.11	.04	.47
Chromium	.23	.10	.06	.47
Copper	.15	.09	.04	.50
Iron	12	9.1	1.3	58.7
Lead	.46	.38	0.1	2.86
Magnesium	10	4.0	3.6	24
Manganese	.67	.42	.12	3.2
Nickel	.15	.05	.09	.29
Zinc	.36	.37	.09	4.6
Alkalinity	56	30	24	124

2. Urban land use variations within the study area were not found to influence the quality of urban land runoff.

3. The standard biochemical oxygen demand test (BOD) was not found to be an appropriate qualitative test for urban land runoff. This was believed due to inhibitory effects and/or inherent problems with the standard test. Chemical oxygen demand test (COD) is believed to be the most consistent measurement of relative storm strength for three reasons:

    a. COD values were reproducible in the lab and were not affected by particle size and/or inhibitory compounds.

    b. The total organic carbon test (TOC) was not always reproducible within the same sample. This is believed due to the syringe injection technique which would not pass particulate matter and to the small amount of sample that could be injected.

    c. The high heavy metal concentration apparently exceeded the threshold inhibitory concentrations in the BOD test causing great variations in values.

4. Approximately 40 to 50 percent of the COD in urban land runoff is susceptible to biodegradation in twenty days.

5. The oxygen exertion or demand rate (k_1) for urban land runoff varies from 0.06 to 0.27 per day to the base e.

6. A vertical distribution of pollutant concentrations within urban drainage channels was found to exist with concentrations increasing with depth from the surface.

7. Through regression analysis, it was found that the significant independent variables affecting stormwater quality were rate of discharge (CFS) and time from storm start (TFSS) as indicated by the initiation of runoff. The elapsed time from the last storm was not found to be a significant parameter. Pollutant concentrations tended to increase with an increase in rate of runoff and decrease as the time from storm start increased, thus indicating a first-flush effect. The prediction equations for the pollutants investigated in mg/l are presented on the following page.

8. The annual urban runoff pollutant yield during the 1972 calendar year from each acre drained was found to be 938 pounds COD, 187 pounds TOC, 7700 pounds total solids, 1458 pounds total volatile solids, 6691 pounds suspended solids, 797 pounds volatile suspended solids, 6.1 pounds kjeldahl nitrogen, 4.7 pounds total phosphorus, 64 pounds aluminum, 52 pounds calcium, 1.9 pounds cobalt, 1.6 pounds chromium, 1.6 pounds copper, 102 pounds iron, 71 pounds magnesium, 4.9 pounds manganese, 1.2 pounds nickel, 2.9 pounds lead, and 2 pounds of zinc.

9. During wet periods (approximately 20 percent of the 1972 calendar year) the yield of organics measured as COD in urban runoff was approximately 4-1/2 times the organic yield of raw sewage while the suspended solids yield in urban runoff was approximately 100 times that in the raw sewage.

REGRESSION EQUATIONS PREDICTING POLLUTANT CONCENTRATION (MG/L) IN URBAN LAND RUNOFF IN A NATURAL CHANNEL CORRECTED TO FLOW AT MID-DEPTH*

Pollutant	MG/L
COD	$113.\ CFS^{0.11}\ TFSS^{-0.28}$
TOC	$32.\ CFS^{0.0}\ TFSS^{-.28}$
TS	$420.\ CFS^{0.14}\ TFSS^{-.18}$
TVS	$130.\ CFS^{0.09}\ TFSS^{-.11}$
TSS	$222.\ CFS^{0.23}\ TFSS^{-.16}$
VSS	$44.\ CFS^{0.18}\ TFSS^{-.17}$
Kjel. N.	$0.85\ CFS^{0.87}\ TFSS^{-.29}$
Total P.	$0.80\ CFS^{0.03}\ TFSS^{-.29}$
Al**	$10.\ CFS^{0.05}\ TFSS^{-.15}$
Ca	$12.5\ CFS^{-.4}\ TFSS^{-.09}$
Co**	$0.07\ CFS^{-.18}\ TFSS^{+.13}$
Cr	$0.18\ CFS^{-.04}\ TFSS^{+.06}$
Cu**	$0.08\ CFS^{0.10}\ TFSS^{+.08}$
Fe	$4.6\ CFS^{0.24}\ TFSS^{-.18}$
Pb	$0.27\ CFS^{0.125}\ TFSS^{-.29}$
Mg	$10.\ CFS^{-.02}\ TFSS^{-.16}$
Mn	$0.45\ CFS^{0.11}\ TFSS^{-.27}$
Ni**	$0.12\ CFS^{0.03}\ TFSS^{+.01}$
Zn	$0.22\ CFS^{0.10}\ TFSS^{-.22}$

*CFS = Cubic Feet Per Second
*TFSS = Time from Storm Start (hours)
** = Mid-depth Correction assumed as 0.9

10. Approximately 20 percent of the time downstream water quality was judged to be primarily governed by non-point urban land runoff.

11. Fifteen minutes of ideal quiescent settling of urban land runoff will remove an average of 60 percent of the COD, 77 percent of the suspended solids, and 50 percent of the turbidity.

12. Alum, with or without coagulant aids, was judged the most effective coagulant in COD, suspended solids, and turbidity removal. Average removal efficiencies, based on jar test results with alum, indicated 84, 97, and 94 percent of the COD, suspended solids, and turbidity, respectively, could be removed with an average dose resulting in an initial concentration of 50 to 60 mg/l.

13. Significant improvements in downstream oxygen levels may be obtained through the use of storage impoundments to exploit the effects of plain sedimentation.

14. It is conceivable that the use of the 7-day, 10-year low flow criterion for controlling water quality is misleading. During this study, it appeared that critical water quality conditions are not typified by the 10-year, 7-day low flow but by the period immediately following low flow when rainfall removes accumulated urban filth into the receiving watercourse, greatly increasing the pollutant load, while not substantially increasing water quantity.

15. Certain forms of solid waste such as beer cans, broken glass bottles, garbage, bed springs, and shopping carts were found in the Third Fork Basin. These solid wastes, believed to be typical of urban streams, not only contribute to lower water quality but are aesthetic pollutants and a hazard to public safety as well.

16. The EPA Storm Water Management Model predicts fairly accurately the hydrograph resulting from the specific storms evaluated. It does not, however, accurately predict pollutant concentrations for the natural stream beds existing in Durham, North Carolina.

17. Results of a hypothetical evaluation of the impact of urban land runoff on downstream water quality in Third Fork Creek indicate that during storm flows, dissolved oxygen content of the receiving watercourse is independent of the degree of treatment of municipal wastes beyond secondary treatment. Oxygen sag estimates are unchanged even if the secondary plant is upgraded to zero discharge. Therefore, if a desired water quality is to be maintained during storm flow conditions, stormwater treatment is necessary.

18. Before upgrading secondary municipal waste plants, concomitant steps should be taken to moderate the adverse effects from urban land runoff.

19. The relative economics of stormwater treatment are highly sensitive to such local parameters as the nature of quality standards, the nature of existing facilities, and the degree of stormwater treatment required.

SECTION II

RECOMMENDATIONS

More extensive study of urban runoff is obviously necessary. At the same time efforts should be made to educate the public to the nature and importance of this non-point waste source. It may be easier to let the public rest, believing point source treatment is the complete answer, but in the long run such a course is not in the best interest of water pollution control. Optimum allocation of public funds for water quality management cannot be realized until sufficient information is available on all pollutant sources potentially capable of impairing water quality.

Urban land runoff is a significant non-point source of pollution; guidelines indicating specific stormwater control standards may soon be issued for urban areas where downstream water quality is partially controlled by urban land runoff. Such regulations typically specify minimum dissolved oxygen concentrations. At present it is virtually impossible to predict, with any assurance of accuracy, the variations of constants associated with oxygen-sag equations during urban runoff events. These constants (k_1, k_2, and k_3) have been evaluated for extreme low-flow situations, but no indepth studies of constant variations associated with high flows exist. It is, therefore, recommended that studies be initiated to define the magnitudes of k_1, the oxygen exertion rate constant; k_2, the reaeration rate constant; and k_3, the rate of removal of oxygen demand by sedimentation during high flows.

The relative effect of urban land runoff on water quality management can be assessed only when the contributions of other non-point sources are quantified. Consequently, additional information is required on all non-point pollution sources including but not limited to forested areas, farmlands, pasture land, and park land. Only by being able to describe accurately the total input of point and non-point sources during wet weather can decisions be made with any certainty.

Urban areas planning to upgrade secondary sewage treatment plants because of possible contravention of stream standards should carefully assess the potential contravention by urban land runoff.

The chemical oxygen demand (COD) test should be considered the most reliable analytical method of assessing the organic content of urban land runoff. The COD uptake technique should be utilized to assess the fraction of COD susceptible to biodegradation and to determine oxygen demand rates.

Watercourses designated as water quality limited should be evaluated with respect to the relative impact of non-point pollution sources.

The scale effect of varying urban drainage basin size on annual pollutional yield from urban land runoff needs additional evaluation.

A full-scale evaluation of the efficiency, economics, and applicability of a holding-sedimentation facility to reduce the impact of urban land runoff on water quality should be made. Included within this study should be a careful assessment of the visual effect of the device and the public's acceptance of the facility.

If partial or total treatment of urban land runoff is desirable, combined sewers offer economic advantages over separate systems. It is, therefore, recommended that municipalities re-evaluate the advantages of separate versus combined sewers.

The EPA Storm Water Management Model does not satisfactorily predict solids and organic concentrations in the Durham watershed. It is, therefore, recommended that the predictive algorithm be re-examined. It is also recommended that COD be substituted for BOD as the predictive organic parameter.

SECTION III

INTRODUCTION

The most obvious, easily recognizable sources of water pollution are untreated or undertreated domestic and industrial wastes. In urban areas, untreated point sources pose the greatest single threat to water quality. Consequently, point sources have long been studied, and much has been learned which can and is being used to diminish or in some cases eliminate the influence of point waste sources on water quality. This fight against point source pollution has been greatly aided by public willingness to allocate funds to provide more and better treatment plants in attempts to protect water quality. Indeed, improved plant performance has become virtually synonymous with increased water quality.

Unfortunately, better treatment plants as they are most often designed do not always produce proportionate improvement in overall water quality. A sewage treatment plant, however sophisticated, can only treat that portion of the total urban pollution load it receives. While urban point waste sources are treated and are becoming less threatening, other non-point sources of water impairment become relatively more significant. As non-point sources typically do not enter treatment facilities and since they have not been sufficiently evaluated, they constitute a double hazard.

First, there is the risk of public disillusionment. A community may make expensive sewage treatment plant improvements and still fail to achieve adequate water quality. Resulting public outrage or worse, apathy, could potentially result in reduced appropriations for much needed water quality management projects.

The second danger is that point source treatment may satisfy a complacent public. A discussion of a recent Council on Environmental Quality study indicated that in 80 percent of the urban areas studied, downstream quality was not controlled by point sources (2).

Non-point urban runoff is generated by precipitation which washes and cleanses an urban environment, and then transports the dirt, filth, etc. to the nearest natural or man-made watercourse. Considering that precipitation cleanses homes, cars, streets, industries, shopping centers, etc. it is not surprising that urban surface waters contain substantial amounts of organics, solids, nutrients, heavy metals, and micro-organisms. Urban surface waters are typically collected in storm sewers, combined sewers, or may appear as diffuse surface water and flow into the nearest urban stream or artificial channel. In any event, the impact of this waste source on water quality management objectives is significant.

More extensive study of urban runoff is obviously necessary. At the same time efforts should be made to educate the public to the nature and importance of this non-point waste source. It may be easier to let the public rest, believing point source treatment is the complete answer, but in the long run, such a course is not in the best interest of water pollution control. Optimum allocation of public funds for water quality management cannot be realized until sufficient information is available on all pollutant sources potentially capable of impairing water quality.

Domestic and industrial raw waste loads can be characterized in pollutant generation per capita per day and gallons per capita per day, whereas waste loads cannot be accurately quantified presently for urban land runoff. The effect of domestic and industrial sewage on water quality can be projected with some degree of reliability because its dominant characteristics are known, whereas such projections cannot be made for urban land runoff because it has not been adequately described. Facility designs of municipal waste treatment plants are based on known pollutant quantities from continuous sources, whereas stormwater facilities have to be based on separate or intermittent surges. Cost information is available for providing a desired degree of amelioration of point sources, whereas similar information does not exist for urban land runoff.

Stream standards historically have been used to provide a baseline against which the relative impact of a waste on a receiving watercourse is measured. The oxygen-sag model is used to predict minimum dissolved oxygen concentrations for given hydrologic conditions; typically, the 10-year, 7-day low flow. During this extreme low-flow situation, one assumes no contribution by non-point sources as extreme low flows are indicative of no rainfall which means no runoff. However, it is conceivable that critical conditions are not typified by the 10-year, 7-day low flow but by the period immediately following the 10-year, 7-day low flow when rainfall removes accumulated urban filth into the receiving watercourse, greatly increasing the pollutant load while not substantially increasing water quantity.

Several questions must be raised. At what time should municipalities become concerned with urban runoff in relation to overall water quality? When is it more economical to provide some degree of urban runoff amelioration to achieve specified decreases in total urban pollutional loads? Is sufficient information available for regulatory agencies to adopt urban runoff treatment requirements? If a municipality desires to reduce the urban runoff pollutional load, what is the least cost alternative to achieve a given reduction? Is sufficient information available to make these decisions?

Project Scope and Objectives

This project was initiated to provide information inputs to the above questions. The specific objectives and scope of work were:

1. To characterize urban stormwater runoff with respect to quantity and quality and land use,
2. To investigate and evaluate the applicability and effectiveness of physiochemical treatment of urban runoff,

3. To develop criteria for ascertaining the point at which an increased degree of municipal waste treatment exceeded the collection and treatment costs of urban runoff required to achieve the same overall water quality management objectives, and

4. To evaluate the applicability of the Environmental Protection Agency's Storm Water Management Model (SWMM) in predicting the quality and quantity of urban runoff.

The urban drainage basin utilized in the study was the Third Fork Basin located in Durham, North Carolina, the site of an earlier study by Bryan (1).

SECTION IV

BASIN DESCRIPTION AND LAND USE

The Third Fork Creek drainage basin selected for study is located in the south central portion of Durham, North Carolina, and is part of the New Hope, Haw, and Cape Fear system. The City of Durham, North Carolina, is located on a divide with the northern portion of the city draining into the Neuse River system and the southern edge being a part of the greater Cape Fear system. The upper Third Fork Creek basin has a 1.67 square-mile (1093 acres) drainage basin completely within Durham city limits with its northern boundary being located in the downtown business section. The study area is served by a separate sanitary system. Figure 1 shows the location of Durham, North Carolina, within the State of North Carolina and the location of the Third Fork Creek drainage basin within Durham.

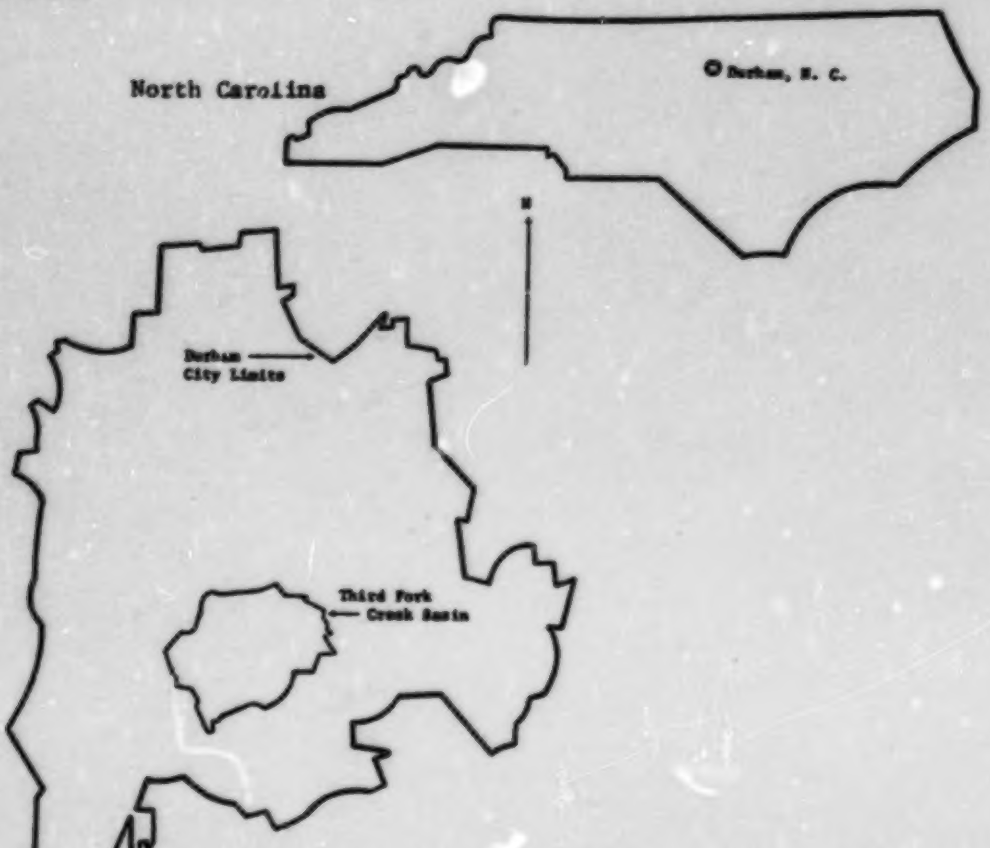


Figure 1. Third Fork Creek study area location within Durham city limits and North Carolina

Third Fork Creek drainage basin is primarily composed of two shallow valleys with relatively narrow flood plains located along the lower portion of each. Excess surface waters in the basin flow into the headwaters of Third Fork Creek through natural and man-made channels. The stormwater runoff system is composed of overland flow, street gutters, small pipes, and culverts under roads. No storm sewer system, as such, exists; therefore, excess surface waters generally follow natural drainage patterns except for a small part of the northern edge of the drainage basin located in the downtown business district, denoted as Subbasin N-2 in Figure 2.

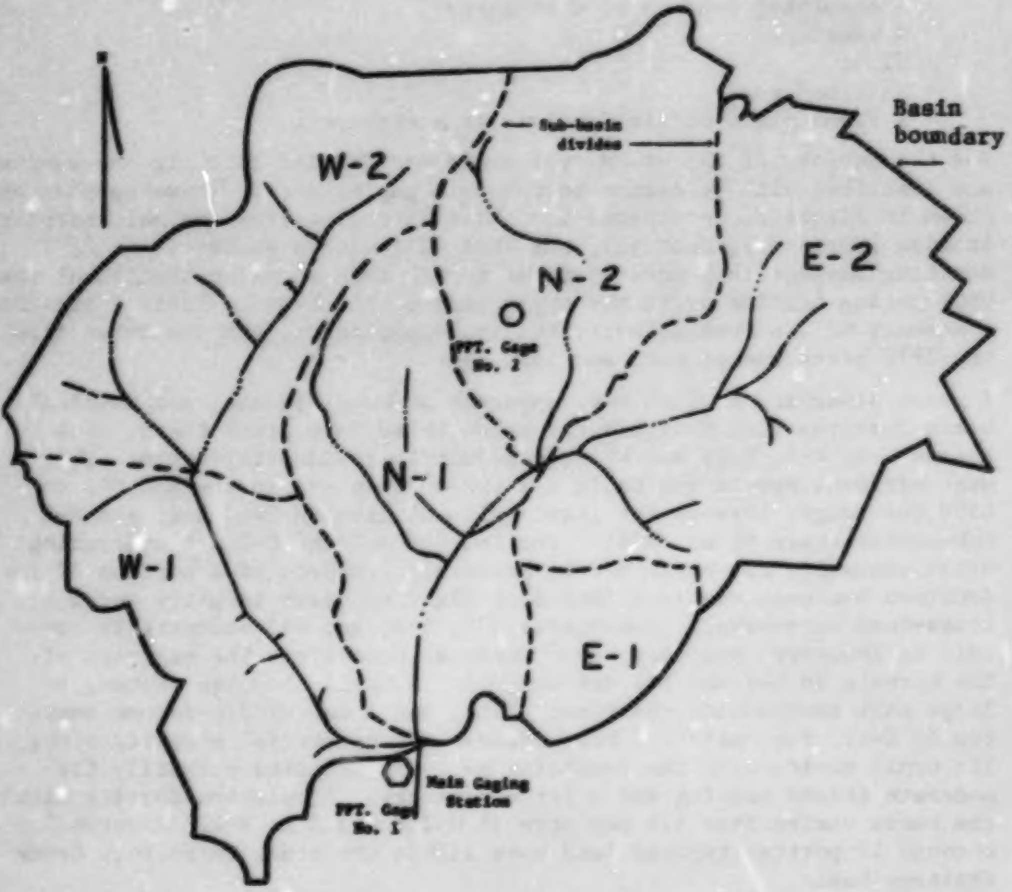

Sub-basin divides
Basin boundary
W-2
N-2
E-2
PPT. Gage No. 2
N-1
W-1
E-1
Main Gaging Station
PPT. Gage No. 1

Figure 2. Drainage pattern of Third Fork Creek within Durham, N. C.

The basin was selected for study as it is representative of a typical urbanized area occurring in the Piedmont region of the Southeastern United States. The basin encompasses the varied land uses as listed below:

- High and low density housing units of varying quality
- Undeveloped land
- Shopping centers
- Portion of the central business district
- Institutional buildings--churches, schools--among scattered, small businesses
- An urban redevelopment section
- A tobacco manufacturing plant
- A completed section of expressway
- A cemetery
- Slums
- Railroad yard
- A flood plain utilized mainly as a city park

For the purpose of the study, the basin was divided into six sub-basins and described with reference to the main gaging site. These sub-basins, shown in Figure 2, were named for their direction from the main sampling station [North (N), East (E), and West (W)] with a number (1 or 2) denoting whether they were adjacent to the main sampling station at the USGS gaging station or in the upper part of the basin. Table 1 presents a summary of land use characterization, population, etc. as taken from the 1970 block census data and topo maps.

A great diversity in land use, apparent personal income, and physical basin features occurs within the urban Third Fork Creek basin. Sub-basins W-1, W-2, E-1, and N-1 are primarily residential areas. The more affluent people reside in W-1 where homes are in the $40,000 to $150,000 range, whereas the least affluent live in E-1, E-2, and N-2 sub-basins where slums exist. Portions of N-2 and E-2 are undergoing urban renewal. Sub-basin N-2 is primarily composed of a portion of the downtown business district including light to heavy industry and a cross-town expressway. Sub-basins E-1, E-2, and W-1 essentially contain no industry, business, or commercial property. The majority of the streets in E-1 and E-2 are unpaved. A small shopping center, a large park surrounding the flood plain, and a few middle-income homes typify N-1. Sub-basin W-2 has business and commercial property along its upper divide with the remaining portions utilized primarily for moderate income housing and a large cemetery. Population density within the basin varies from 1.5 per acre in N-2 to 13.5 in E-1. Figures 3 through 17 portray typical land uses within the urban Third Fork Creek drainage basin.

Pictures portraying the upper prongs of Third Fork Creek within the Durham basin are presented in Figures 18 through 27.

Table 1. THIRD FORK CREEK LAND USE CHARACTERIZATION BY SUB-BASINS

Sub-basin	Area		Population Density Per Acre	Physical Features			% of Residential Dwellings of			Percent Land				Sub-basin Surface Characteristics % of Sub-basin			
	Acres	% of Total		Stream Length Feet	Stream Slope %	Mean Land Slope %	Low Quality	Med. Quality	High Quality	Resident.	Comm. & Indus.	Pub. & Inst.	Unused	Paved	Roof-tops	Unpaved Streets	Vegetation
E-1	56	5.2	13.5	1312	3	9.2	100	0	0	100	0	0	0	5	7	12	76
E-2	263	24.6	6.9	3221	1.4	5.2	100	0	0	50	36	9	5	27	13	3	57
N-1	183	17.1	3.0	3350	1.0	7.4	6	52	42	63	8	19	10	16	5	1	78
N-2	191	17.9	1.5	3464	2.1	8.1	62	31	7	18	44	13	25	33	12	1	54
W-1	169	15.8	3.5	3282	0.9	8.4	0	30	70	85	0	15	0	16	5	3	77
W-2	207	19.4	10.8	2610	1.8	9.1	62	38	0	73	4	9	14	11	9	6	74
Total Basin	1069	100%	6.0	-	-	-	24	27	49	59	19	12	10	20	9	3	68

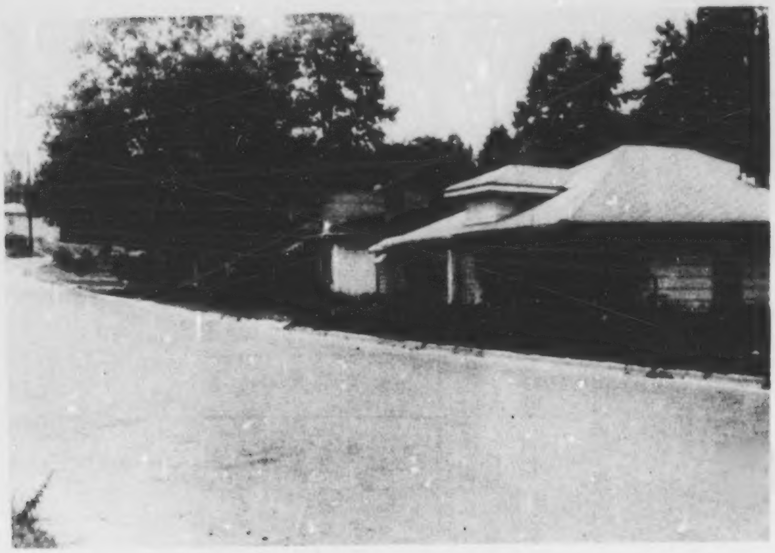


Figure 3. Typical land use in Sub-basin E-1.

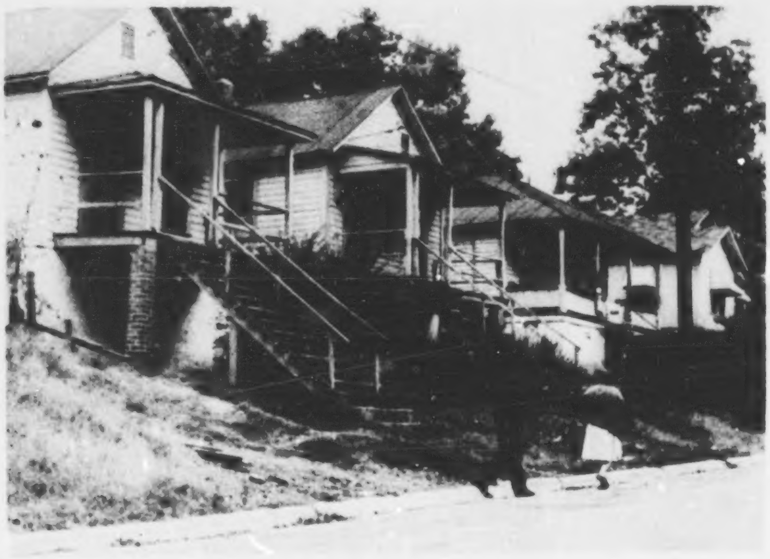


Figure 4. Typical land use in Sub-basin E-1.

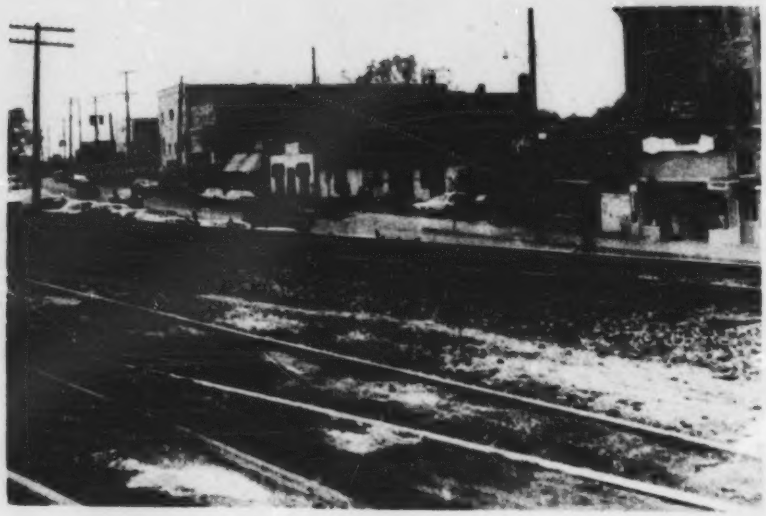


Figure 5. Typical land use in Sub-basin E-2.

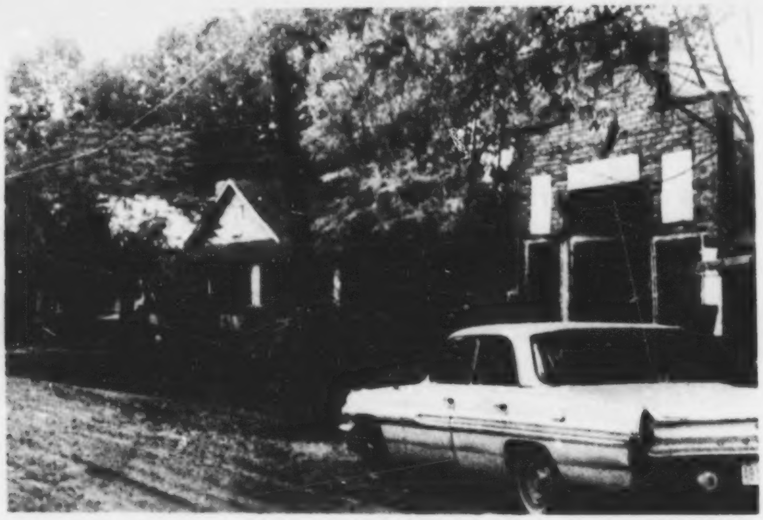


Figure 6. Low-income housing in Sub-basin E-2.

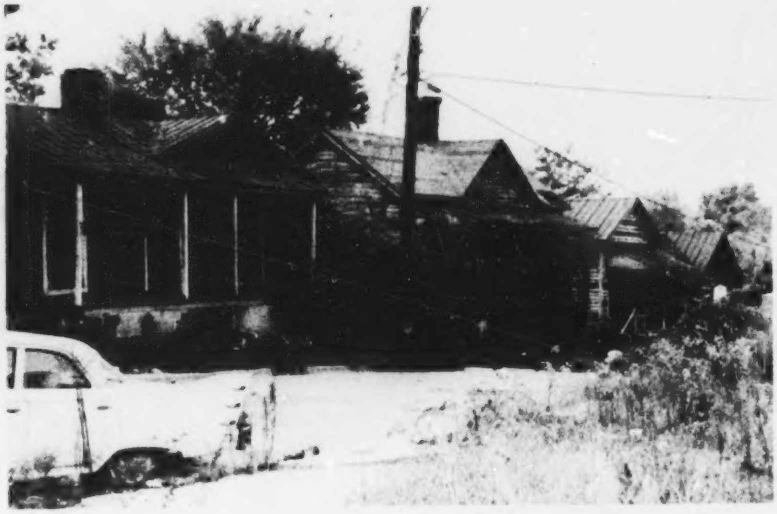


Figure 7. Typical land use in Sub-basin E-2.

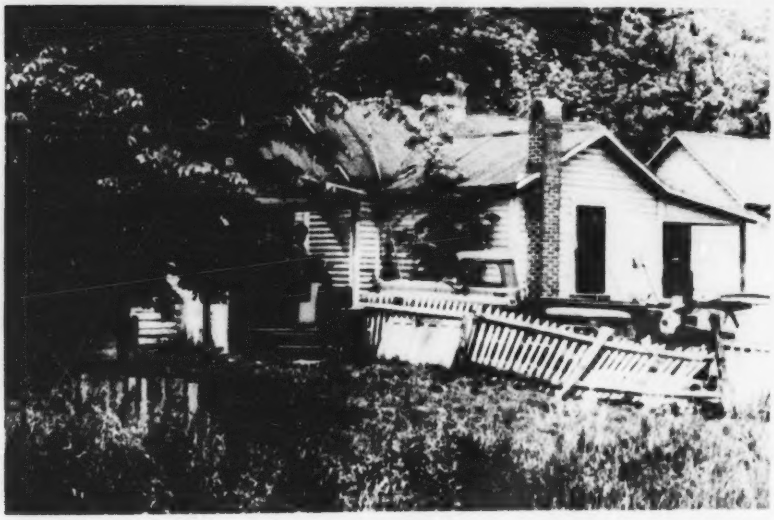


Figure 8. Typical land use in Sub-basin N-1.

Figure 9. Small shopping center in Sub-basin N-1.

Figure 10. City Park surrounding Third Fork Creek in Sub-basin N-1.

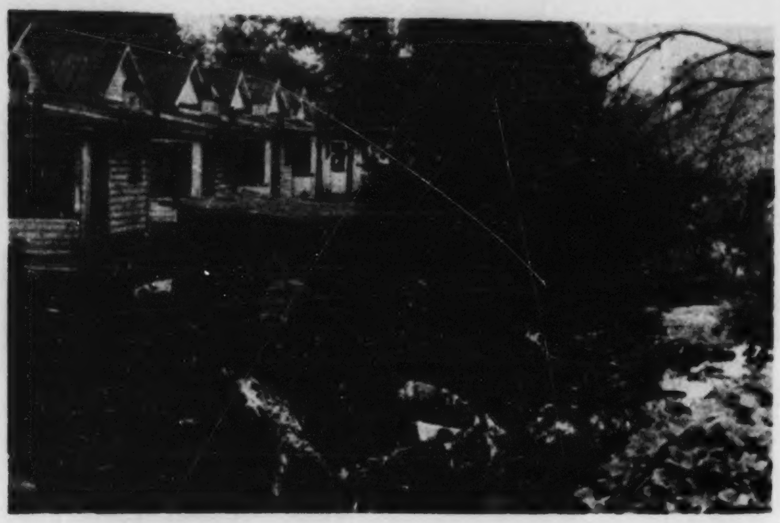


Figure 11. Typical land use in Sub-basin N-2.

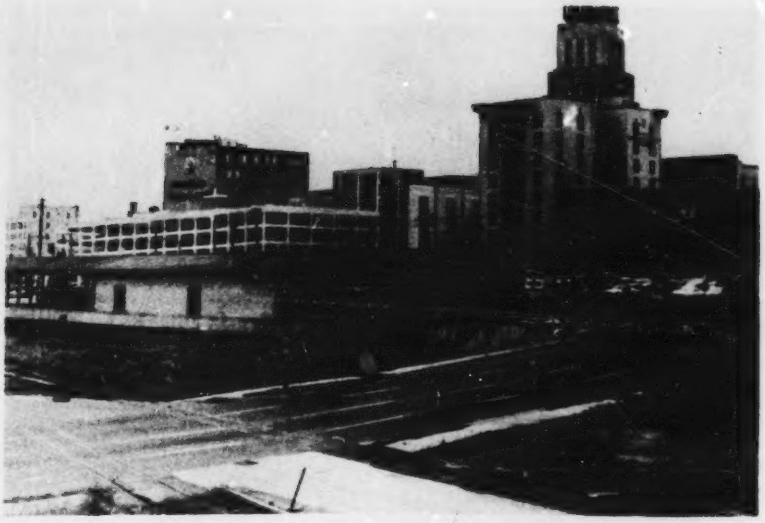


Figure 12. Typical land use in Sub-basin N-2.

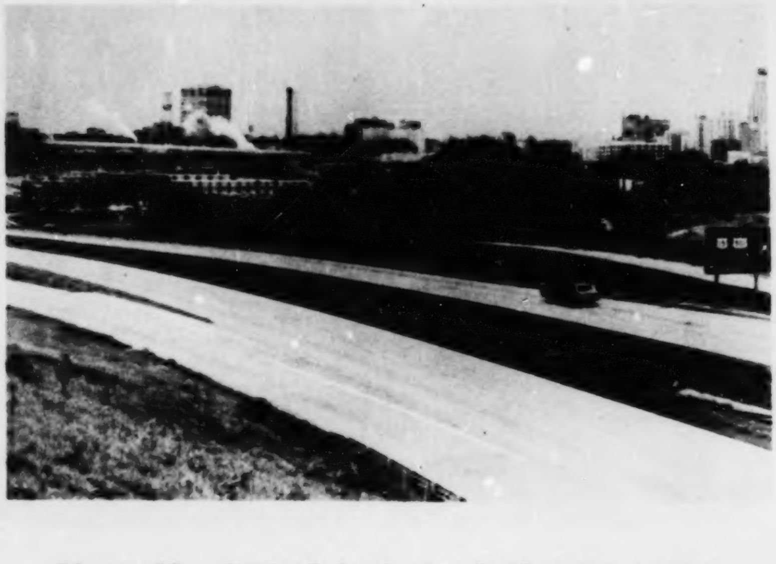


Figure 13. Typical land use showing cross-town expressway in Sub-basin N-2.

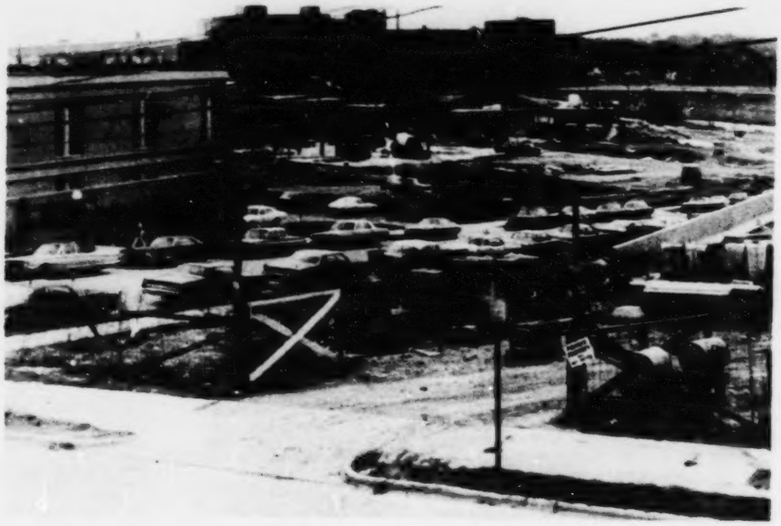


Figure 14. Typical land use in Sub-basin N-2.

Figure 15. Typical land use in Sub-basin W-1.

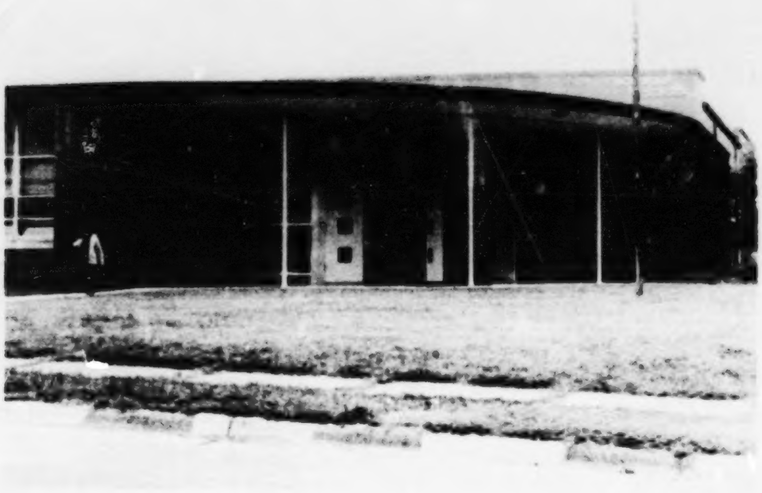


Figure 16. Public school in Sub-basin W-2.

Figure 17. Typical land use in Sub-basin W-2.

Figure 18. Third Fork Creek above gaging station.

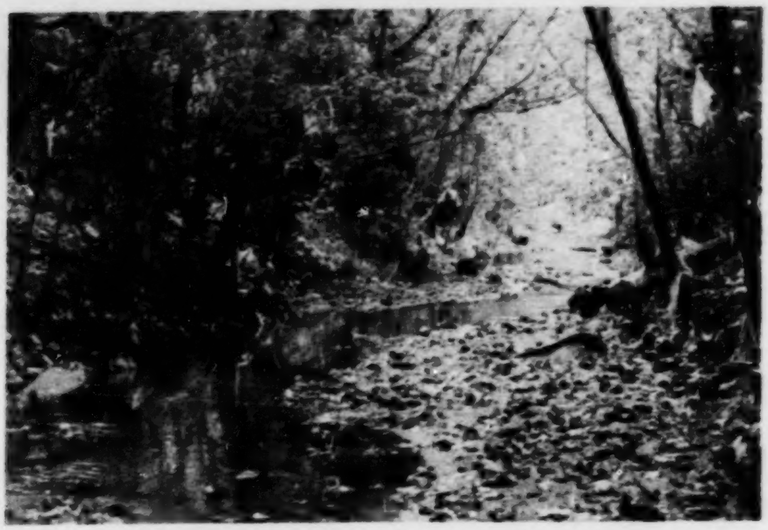


Figure 19. Third Fork Creek channel behind small shopping center.

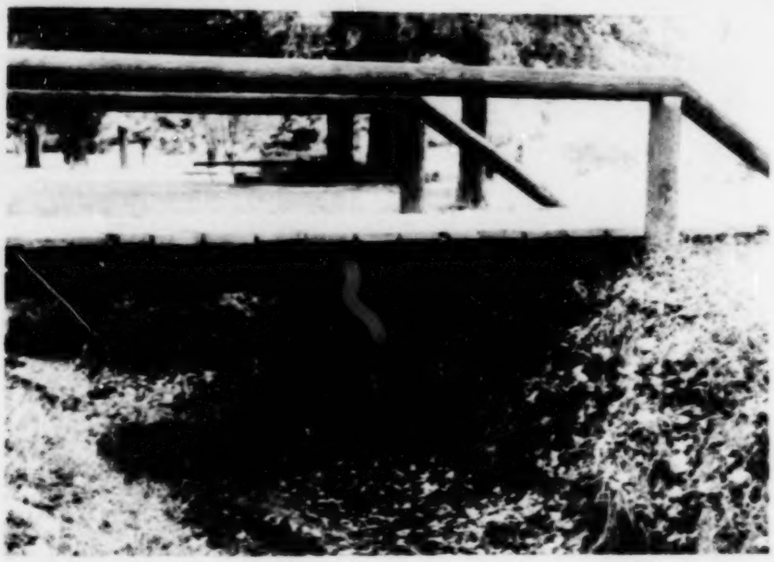


Figure 20. Prong of Third Fork Creek in Sub-basin N-1.

Figure 21. Culvert in Sub-basin W-1.

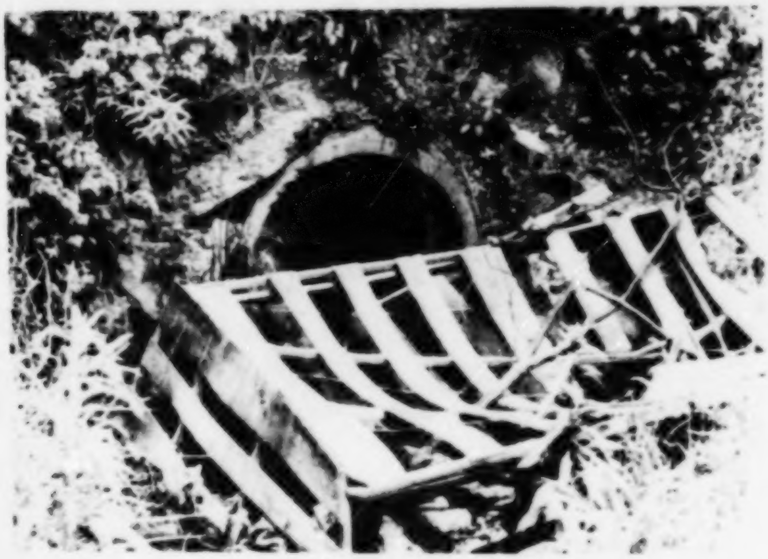


Figure 22. Trash in creek in Sub-basin W-2.

Figure 23. Trash in creek in Sub-basin N-1.

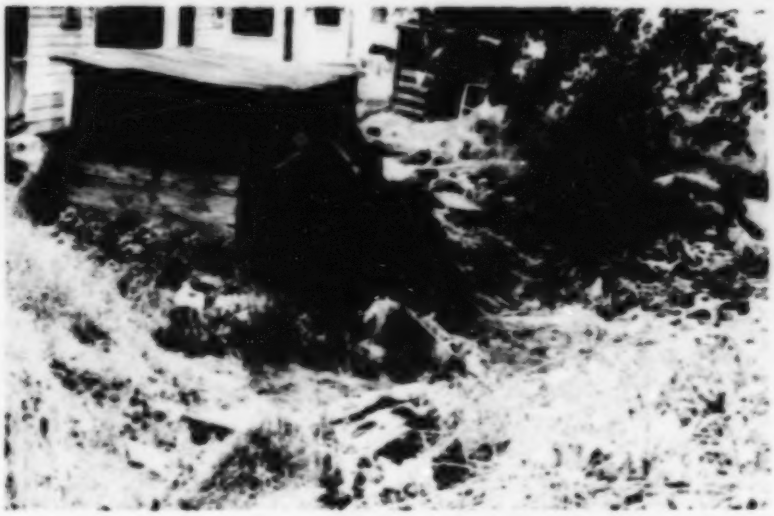


Figure 24. Trash in stream in Sub-basin N-1.

Figure 25. Stream in Sub-basin W-2.

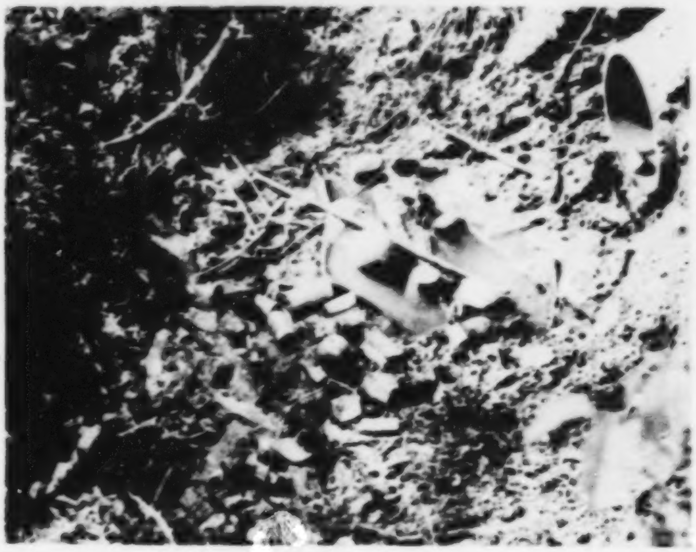


Figure 26. Trash in stream in Sub-basin W-2.

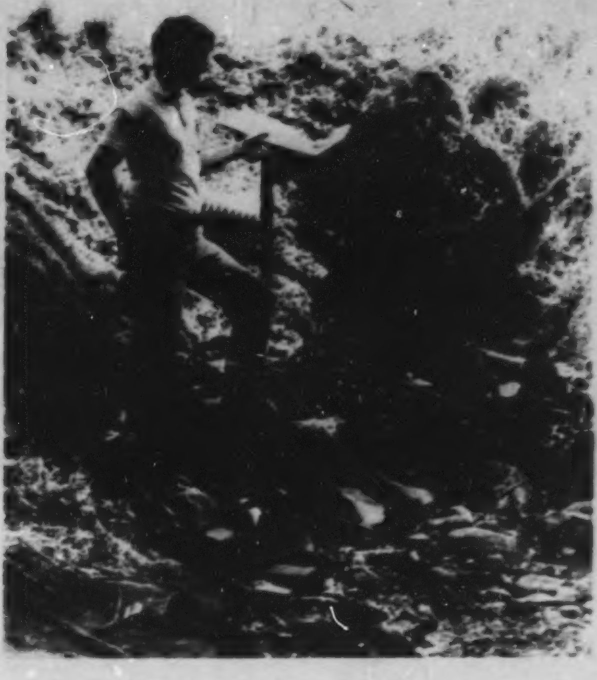


Figure 27. Trash in stream bed in Sub-basin W-2.

SECTION V

SAMPLING

Hydrologic Data

The United States Geological Survey operates a continuous stage recorder (Station No. 02097243) and two digital punch tape recorders within the 1.67 square-mile drainage basin. The stage recorder and one precipitation station are located at the main gaging site at the bottom of the selected drainage basin.. The gage house, shown in Figure 28, is located on the right bank of the Third Fork Creek, 62 feet downstream from a bridge on Forest Hills Boulevard and 7 miles upstream from the mouth of Third Fork Creek. Stream-flow control is provided by a V-notch weir.

Automatic Sampler

The procurement of samples during periods of runoff presented a problem as no readily available commercial samplers were judged satisfactory for the conditions at the sampling location. The special requirements were:

1. Samples had to be obtained directly out of the stream located adjacent to the USGS gage weir.
2. The sampler had to be small enough to not interfere with the flow of water over the weir and not act as an obstruction to catch debris washed downstream during storms.
3. The sampler had to be able to pass large quantities of sand, leaves, and other solids without clogging and yet be immune to damage from larger floating objects such as beer cans, railroad cross ties, tire carcasses, and shopping carts.
4. The sampling mechanism had to have the capability of starting by itself during each runoff event when the stage reached a predetermined level indicating initiation of runoff. [This was necessitated by the basin being approximately thirty miles from the University and mainly because it is impossible to estimate initiation of runoff from weather forecasts. It appeared that most events started after midnight and before 8:00 a.m.]
5. The sampling system had to be able to take discrete samples at predetermined intervals with a known time of the first sample and last sample. This was needed to correlate water quality with the exact quantity and time of runoff.
6. The entire system had to be free from potential vandalism.
7. An appearance before the Durham City Council was required to allay fears of nearby citizens that the sampling station would be an unsightly addition to the park.

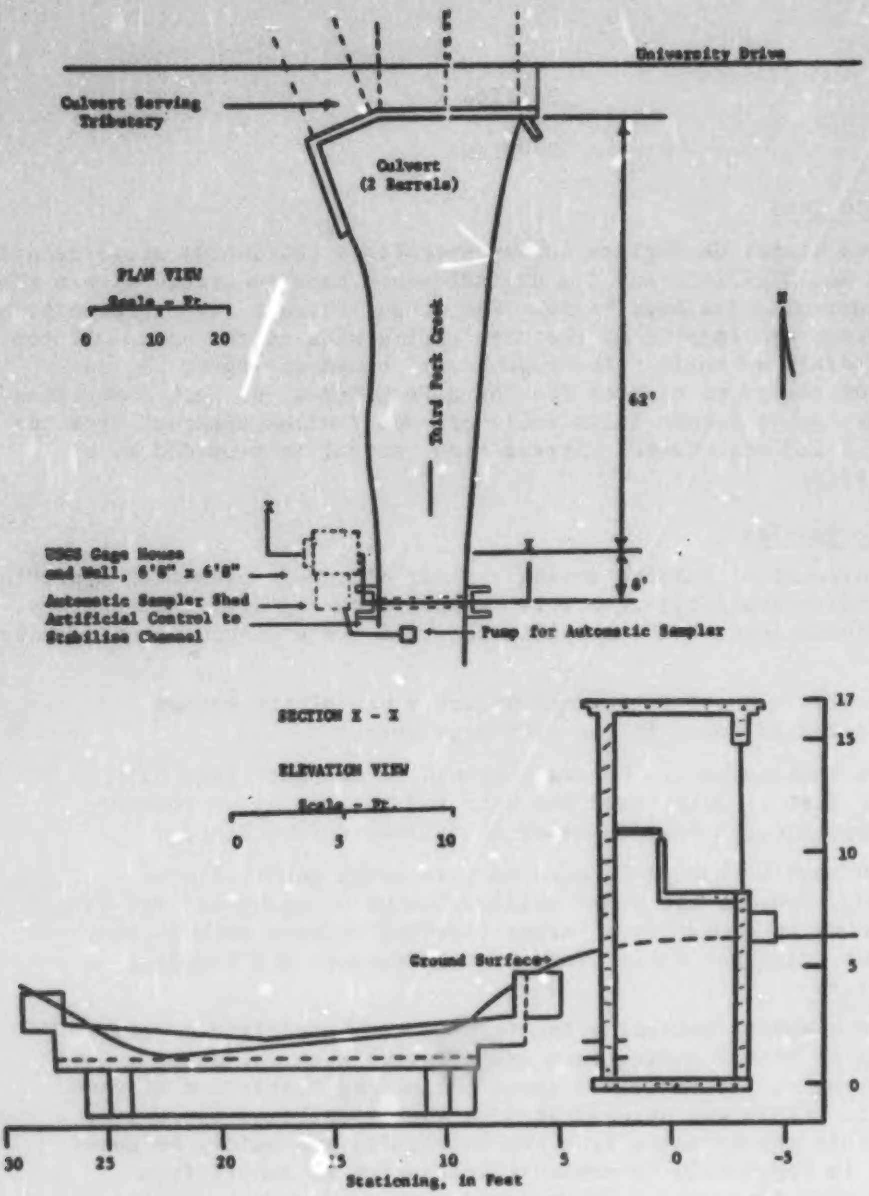

University Drive
Culvert Serving Tributary
Culvert (2 Barrels)
PLAN VIEW
Scale - Ft.
0
10
20
N
Third Fork Creek
62'
X
USGS Gage House and Well, 6'8" x 6'8"
Automatic Sampler Shed
Artificial Control to Stabilize Channel
X
8'
Pump for Automatic Sampler
SECTION X - X
ELEVATION VIEW
Scale - Ft.
0
5
10
17
15
10
5
0
Ground Surface
30
25
20
15
10
5
0
-5
Stationing, in Feet

Figure 28. Schematic diagram showing location and relative elevations of USGS gage house and control weir.

8. The water velocity through the system had to be sufficient to keep all material in suspension to obtain representative samples and minimize system clogging.

The system designed and installed to meet the desired objectives consisted of the following main items:

1. A 1/2 H.P. Enpo-Cornell Model 150 submersible pump with mechanical seal and cast iron impeller capable of pumping 50 GPM against a 12-foot head.
2. An electronic control box capable of sensing increases in stage with a 1 to 60-minute interval timer.
3. A plexiglass sampling flume 10 inches high, 36 inches long, and 1 inch wide.
4. A 24-bottle Serco vacuum sampler modified with a Minarik motor for sample procurement.

The submersible pump, housed in a steel box with approximately 300 one-inch-diameter holes, was located in the middle of the stream approximately five feet below the USGS weir. The pump box was securely fastened to two 7-foot steel pipes driven into the stream bed holding the pump securely in place. All samples taken, therefore, came from the lower or bottom portion of the runoff hydrograph. Substantial wear occurred to the impeller and volute casing necessitating pump repair and/or replacements. The pump would occasionally become clogged during a runoff event which stopped the sampling procedure.

The electronic control box located in the USGS building provided several control functions. These were:

1. A probe dropped into the wet well at a predetermined elevation corresponding to a 0.7-foot stage so selected as to indicate runoff initiation. When the water in the wet well touched the probe, the sampling system would automatically turn on.
2. One of two clocks running connected to the control panel would turn off indicating the time of sampling initiation.
3. The control panel would turn on the submersible pump. If for some reason the pump did not have at least 7 inches of water flowing through the flume in two minutes, a sensor would turn the system off to protect it from damage.
4. A 1-to-60-minute interval time on the control box was set to select the time period between discrete samples. With 24 sample bottles, samples could conceivable be taken each hour for 24 hours. However, during the period of this study, the selected interval was 30 minutes or less.
5. A plexiglass sampling flume was designed to guarantee no sediment deposition at a flow rate of 50 GPM. The water entered at one end of the flume and was discharged back to the

creek through a pipe at the other end. The sampling head was attached close to the discharge end of the flume.

6. The Serco vacuum sampler had 24, 0.5-liter sample bottles. Prior to sampling, a vacuum was placed in the bottles by means of a vacuum pump with a special head designed to fit over the sampling head when removed from the flume. The vacuum pump was allowed to run 5 minutes to ensure a maximum vacuum on each bottle. The vacuum pump was then removed, and the sampling head securely fastened to the sampling flume.

7. A slow-speed Minarik motor was vertically attached to the outside of the sampler body and connected to a vertical shaft by a chain and two sprockets. The larger sprocket, attached to the center shaft, had 24 screws placed through the rim. Each screw indicated 1/24 of a revolution or how much rotation was needed by the shaft to release the vacuum on each sample bottle when indicated by the interval time. A relay switch, attached to the body of the sampler and activated by coming into contact with the screws in the sprocket, turned the motor off when sufficient movement had occurred to release the vacuum on the selected bottle. When the vacuum was released, the bottle would draw in approximately 350 milliliters of sample from the sampling flume. When the 24th sample was taken, the sampling system would automatically turn off, activating a second clock indicating the time of the last sample.

Although the sampling system was not 100 percent reliable, it was judged to be fairly reliable considering the type of material being sampled and the adverse conditions under which sampling occurred.

A schematic of the automatic sampling system is shown in Figure 29. Illustrations of the gage house and the sampling are given in Figures 30 through 36.

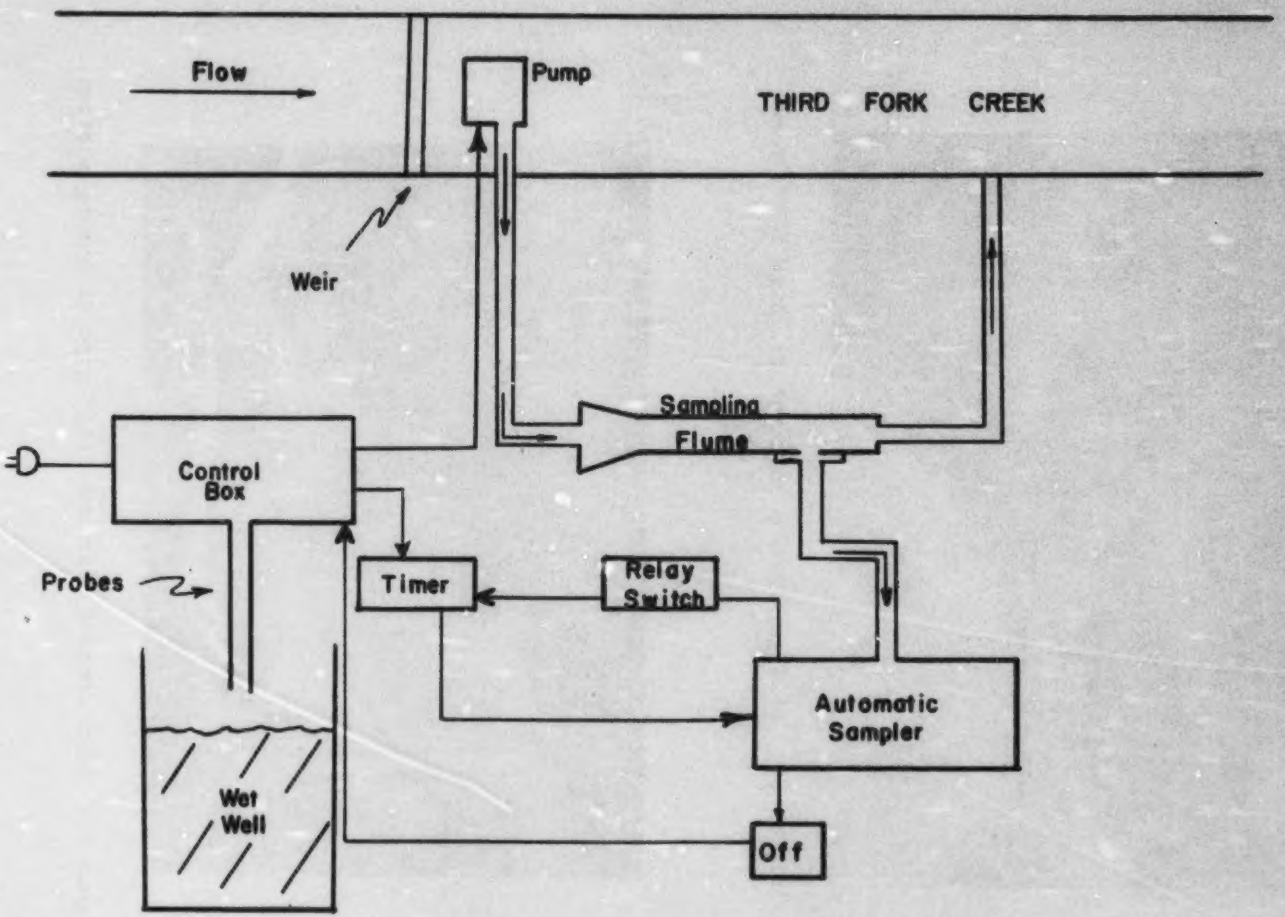

Flow
Pump
THIRD FORK CREEK
Weir
Sampling
Flume
Control
Box
Probes
Timer
Relay
Switch
Automatic
Sampler
Wet
Well
Off

Figure 29. Schematic of automatic sampling system.

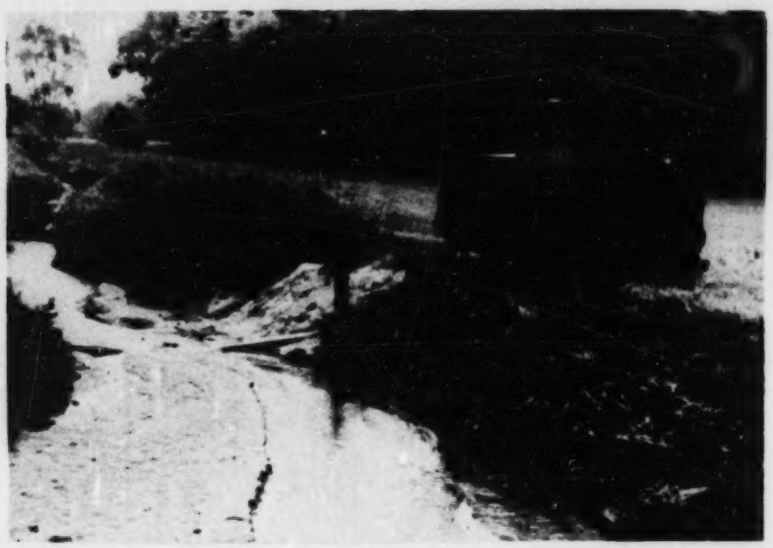


Figure 30. USGS gage house adjacent to Third Fork Creek.

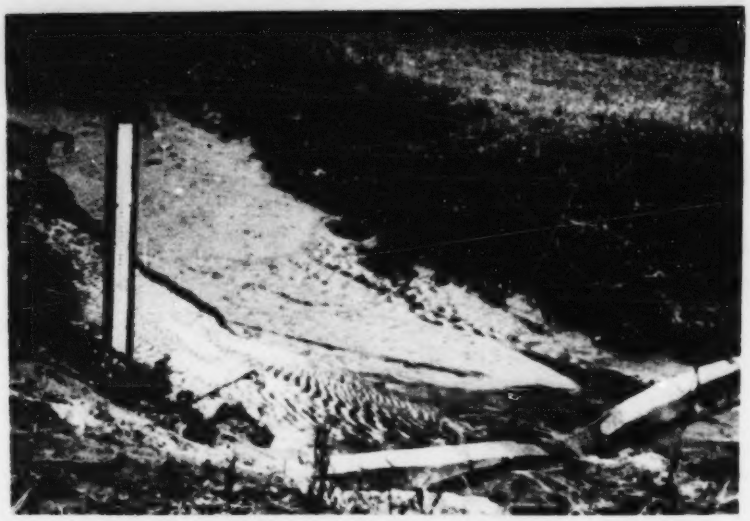


Figure 31. USGS control weir and staff gage at gaging station.

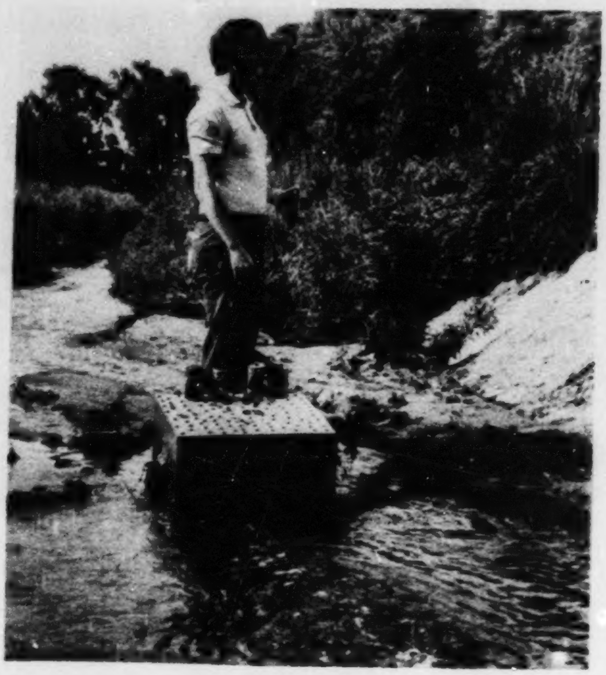


Figure 32. Box housing submersible pump at sampling station.

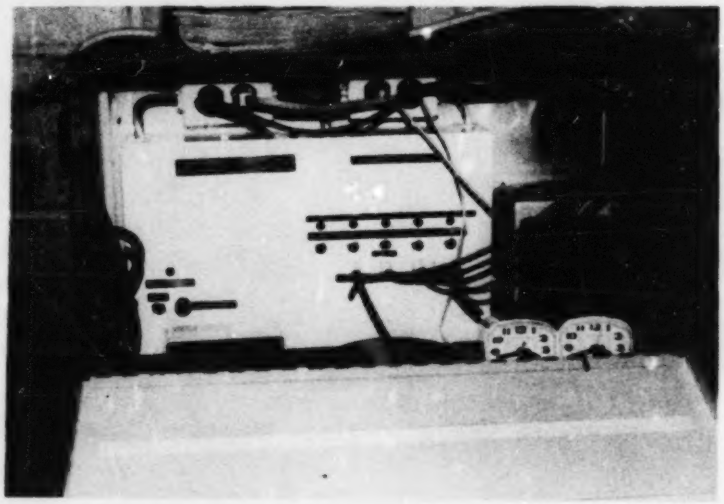


Figure 33. Automatic sampler control box.

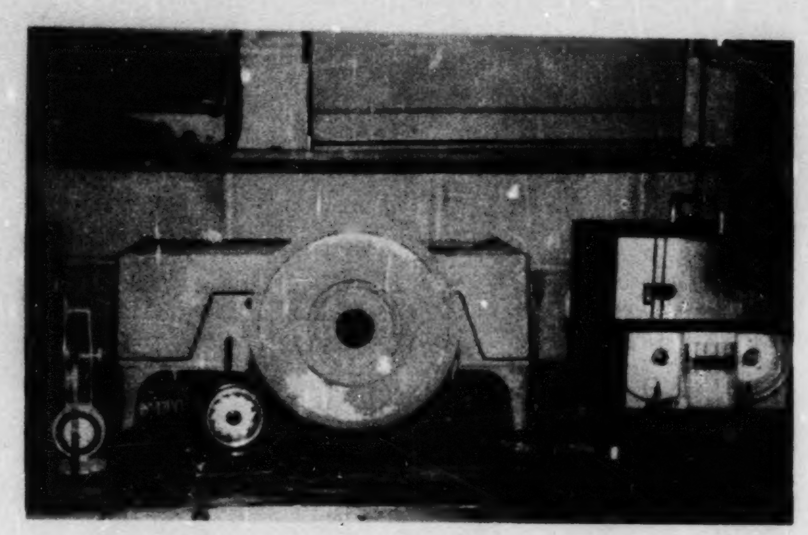


Figure 34. Stage recorder and digital precipitation recorder inside USGS gage house.

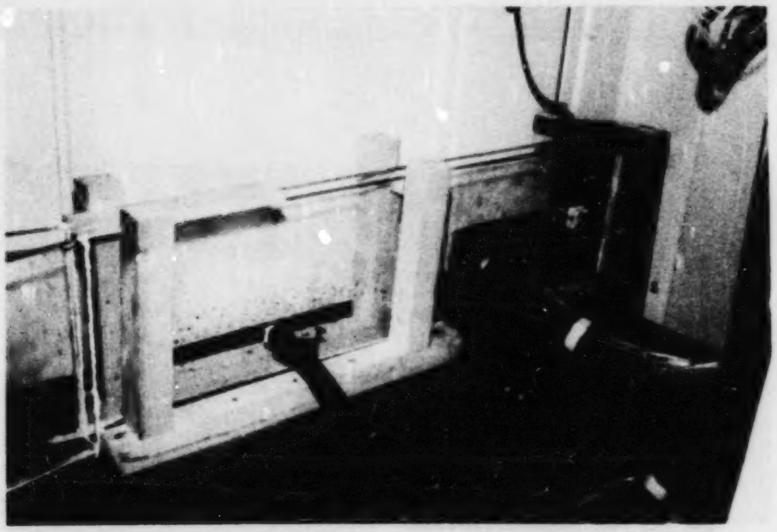


Figure 35. Plexiglass sampling flume.

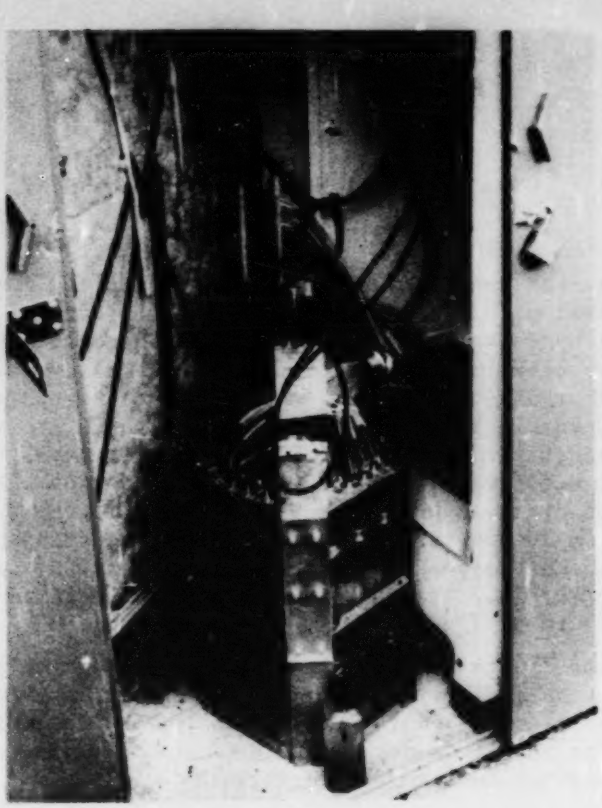


Figure 36. Modified vacuum sampler.

SECTION VI

CHARACTERIZATION OF URBAN LAND RUNOFF

Hydrologic Information

Thirty-six separate runoff events were sampled during the project period producing a total of 521 separate samples. A summary of information describing the hydrologic and time parameters associated with each storm sampled is presented in Table 2. Each storm sampled was assigned a sequential number used here and elsewhere to denote the specific storm sampled. The hydrologic information given for each storm includes the inches of precipitation, storm duration, average intensity, inches of runoff, runoff coefficient, and antecedent dry period. The hydrologic characteristics of the storms vary from a short intense summer thunderstorm (#21) to a 30-hour drizzle (#1). Runoff coefficients vary from 0.006 to 0.90, and the peak discharge associated with each storm varies from 2.25 to 1740 cfs. The number of dry days preceding each storm varies from 0.5 to 34.

Storm Nos. 1 and 2 were manually sampled at the surface prior to adequate installation and operation of the automated sampling system which procured its samples adjacent to the stream bed. The hydrologic information for Storm No. 30 is not available due to a malfunction of the stage and precipitation recording equipment.

The number of samples taken during a storm ranged from 3 to 26. This great diversity in the number of storm samples was due to clogging of the submersible pump by material which caused the sampling system to cut off automatically. This problem seemed excessive during the fall when dead leaves washed from the basin.

The great variance in storm characteristics is believed to reflect the diversity in the occurrence of natural events.

Individual Storm Characterization

The average COD, TOC, and BOD with standard deviations for each storm sampled is presented in Table 3. These three organic indicators were run on each sample where indicated. COD is believed to be the most consistent measurement of relative storm strength for three reasons:

1. COD values were reproducible in the lab and were not affected by particle size and inhibitory compounds.
2. TOC was not always reproducible within the same sample. This is believed due to the syringe injection technique which would not pass particulate matter and to the small amount of sample that could be injected.
3. The high heavy metal concentrations apparently exceeded threshold inhibitory concentrations in the BOD test causing great variations in BOD values.

Table 2. HYDROLOGIC DESCRIPTION OF URBAN RUNOFF EVENTS SAMPLED

Date	Storm No.	Rainfall Inches	Duration Hours	Intensity In/hr	Runoff Inches	Runoff Coefficient	Peak Discharge CFS	Days Since Last Storm	No. Samples Taken
10/23/71	1	1.35	32.5	0.047	0.80	0.54	33.2	3.25	15
11/24/71	2		← NO PRECIPITATION RECORDS AVAILABLE →					34.0	13
12/16/71	3	0.05	0.5	0.1	0.003	0.0061	2.5	4.0	10
12/30/71	4	0.43	19.5	0.022	0.15	0.34	31.3	0.5	16
1/4/72	5	0.2	2.5	0.08	0.04	0.19	22.6	4.75	9
1/10/72	6	0.55	12.0	0.046	0.19	0.34	63.0	1.0	19
2/1-2/72	7	1.19	10	0.119	0.84	0.7	138.4	11.5	27
2/12-13/72	8	0.96	10	0.096	0.34	0.36	128.6	9.0	20
2/18/72	9	0.44	8	0.049	0.2	0.45	32.0	5.5	27
2/23/72	10	0.13	0.5	0.26	0.04	0.29	22.0	3.5	8
2/26/72	11	0.19	0.5	0.38	0.03	0.18	19.0	2.83	23
3/8/72	12	0.04	0.083	0.48	0.01	0.25	4.3	4.88	15
3/16/72	13	0.6	10.33	0.058	0.36	0.59	51.8	7.25	23
3/31/72	14	0.46	11.33	0.04	0.15	0.33	40.6	9.5	23
4/12/72	15	0.33	2.17	0.15	0.12	0.35	73.0	4.25	17
5/3/72	16	1.14	7.25	0.15	0.47	0.41	135.7	21.0	21
5/14/72	17	0.71	8.0	0.089	0.29	0.41	109.0	5.5	24
5/22/72	18	0.92	15.5	0.059	0.513	0.56	349.0	5.0	9
5/30-31/72	19	0.25	10.0	0.025	0.03	0.12	29.9	5.62	8
6/20/72	20	0.24	6.5	0.037	0.07	0.29	75.4	20.5	16
6/28/72	21	1.78	2.13	0.83	1.55	0.87	1740	7.17	5
7/11/72	22	0.1	0.5	0.2	0.005	0.054	2.25	6.54	4
7/12/72	23	0.33	3.83	0.086	0.083	0.25	36.2	7.33	15
7/17/72	24	0.26	1.0	0.26	0.15	0.57	125.0	5.25	7
7/31/72	25	0.38	2.5	0.15	0.34	0.9	132.0	0.75	20
8/28/72	26	0.06	2.1	0.028	0.004	0.066	2.58	6.54	3
9/17/72	27	1.51	3.3	0.45	0.7	0.46	700.0	11.3	10
9/21/72	28	0.5	9.0	0.055	0.083	0.16	41.4	3.5	10
10/5/72	29	2.36	26.0	0.34	2.07	0.88	872.0	5.0	7
10/19/72	30			← RECORDERS INOPERABLE →					11
11/14/72	31	0.74	3.63	0.2	0.25	0.34	120.6	6.0	9
11/19/72	32	0.79	4.0	0.19	0.48	0.61	106.0	2.45	20
11/30/72	33	0.5	14	0.04	0.09	0.18	57	4.6	12
1/19/73	34	0.11	1.25	0.09	0.03	0.30	27.8	4.2	26
2/26/73	35	0.4	1.6	0.25	0.09	0.24	83	12.1	3
3/21/73	36	0.25	5.0	0.05	0.05	0.23	38	4.1	16

Table 3. AVERAGE AND STANDARD DEVIATION OF ORGANICS IN URBAN RUNOFF EVENTS AT THE MAIN GAGING STATION

Storm Number	COD mg/l		TOC mg/l		BOD mg/l	
	Avg.	σ	Avg.	σ	Avg.	σ
1	25	14			18	14
2	239	62				
3	111	21	30	7		
4	171	43	36	7		
5	146	89	35	34	18	13
6	141	60	25	11	17	12
7	195	103	38	41	6	6
8	143	104	33	16		
9	149	116	24	17	2	.4
10	125	96	36	27		
11	171	146	38	25		
12	82	39	36	10	15	11
13	176	144	44	30	20	12
14	123	73	46	20		
15	89	49	36	12	18	9
16	257	190	17	12		
17	150	175	15	8	42	11
18	41	7	16	5		
19	144	106	41	25	5	3
20	120	135	39	18	53	16
21	271	130	73	30	105	23
22	402	430	165	148	73	10
23	96	52	26	9	100	5
24	348	198	94	41	80	19
25	187	79	48	14	16	2
26	184	80	50	18	220	10
27	253	232	51	41	41	24
28	140	60	21	11		
29	142	59	38	16	138	15
30	157	69	44	13	182	60
31	132	83	49	15	80	74
32	110	77	34	10		
33	93	28	38	14	49	20
34	374	103	105	35	50	12
35	289	101	99	19	100	20
36	92	31	31	14		

Individual concentrations for each sample are presented in the Appendix. The variation in COD, TOC, and BOD concentrations and flow rate within two typical storms as a function of time are presented in Figures 37 and 39.

The average and standard deviation of solids for each storm is presented in Table 4. Typical variations in solids concentration with rate of flow and time from initiation of runoff are presented in Figures 37 and 39. The complete solids analysis for each storm is presented in the Appendix.

The average and standard deviation of total phosphorus (as P), kjeldahl nitrogen, and fecal coliforms are presented for each of the storms in Table 5. The comparatively high nitrogen concentration of Storm Nos. 3 and 4 are believed erroneous. The individual nitrogen, phosphorus, and fecal coliform analysis for each sample is provided in the Appendix. Typical variations of kjeldahl nitrogen, total phosphorus and fecal coliform concentration with rate of flow and time since the beginning of the storm are presented in Figures 38 and 40.

The average and standard deviation of metals concentration for the storms sampled are presented in Table 6. The actual metal concentrations for each sample are presented in the Appendix.

The average, standard deviations and range of all pollutants for samples collected are presented in Table 7. It is interesting to note the large variance of pollutant concentrations of urban runoff. These averages represent only those samples procured by the automatic sampler.

Base Flow Characterization

Base flow analyses were made 32 times during the project at the USGS gaging station on Third Fork Creek and less often at individual sub-basin discharge locations. The average base flow water quality for the total basin and the sub-basins are presented in Table 8. The individual observations for each sub-basin are included in the Appendix. The quality of the N-2 sub-basin is worse than for the other basins and is believed due to illegal connections.

Effect of Land Use on Water Quality

In order to assess the impact of varying types of land use within the basin on urban runoff quality, 5 storms were manually sampled at the sub-basin discharge locations. It was believed that a varying quality of urban runoff from the sub-basins should reflect impacts of varying land use.

A control section, usually a pipe or box culvert, was utilized with Manning's equation to arrive at stage discharge relationships for each sub-basin sampled. During the 5 selected storms the stage was manually read when the sample was taken. By knowing the discharge rate for each sample and the corresponding time, a discharge hydrograph for each storm was obtained along with pollutant concentrations.

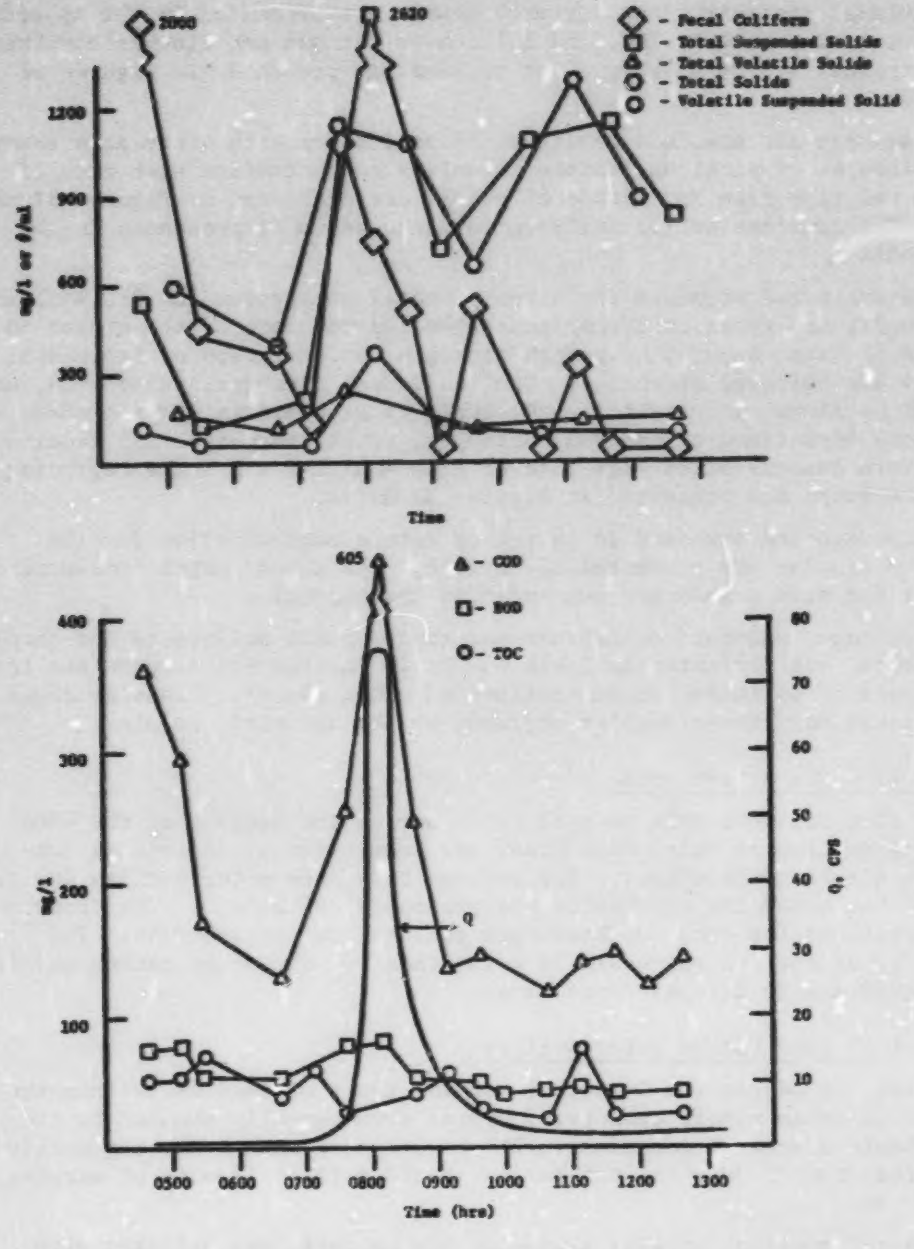


Figure 37. Pollutant variations with Q and time for Storm No. 20, Date 6/20/72.

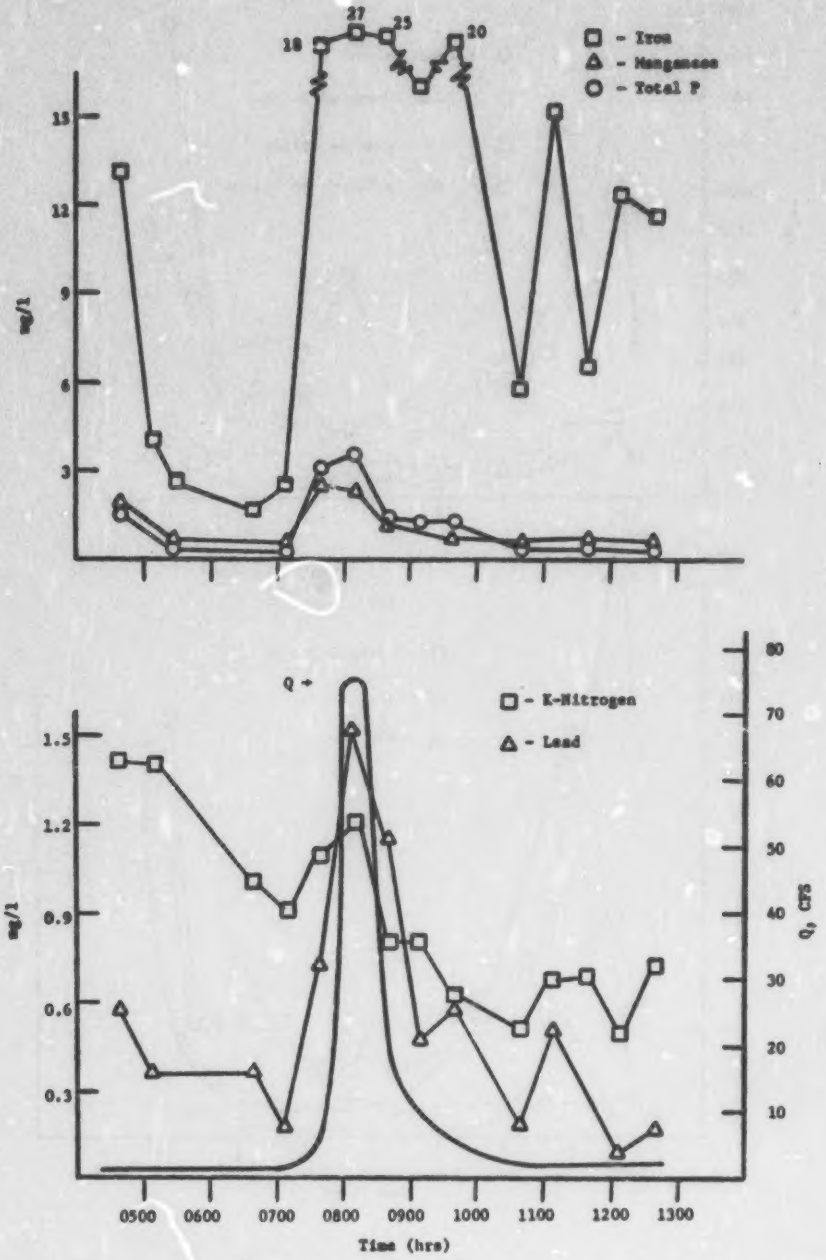


Figure 38. Pollutant variations with Q and time for Storm No. 20, Date 6/20/72.

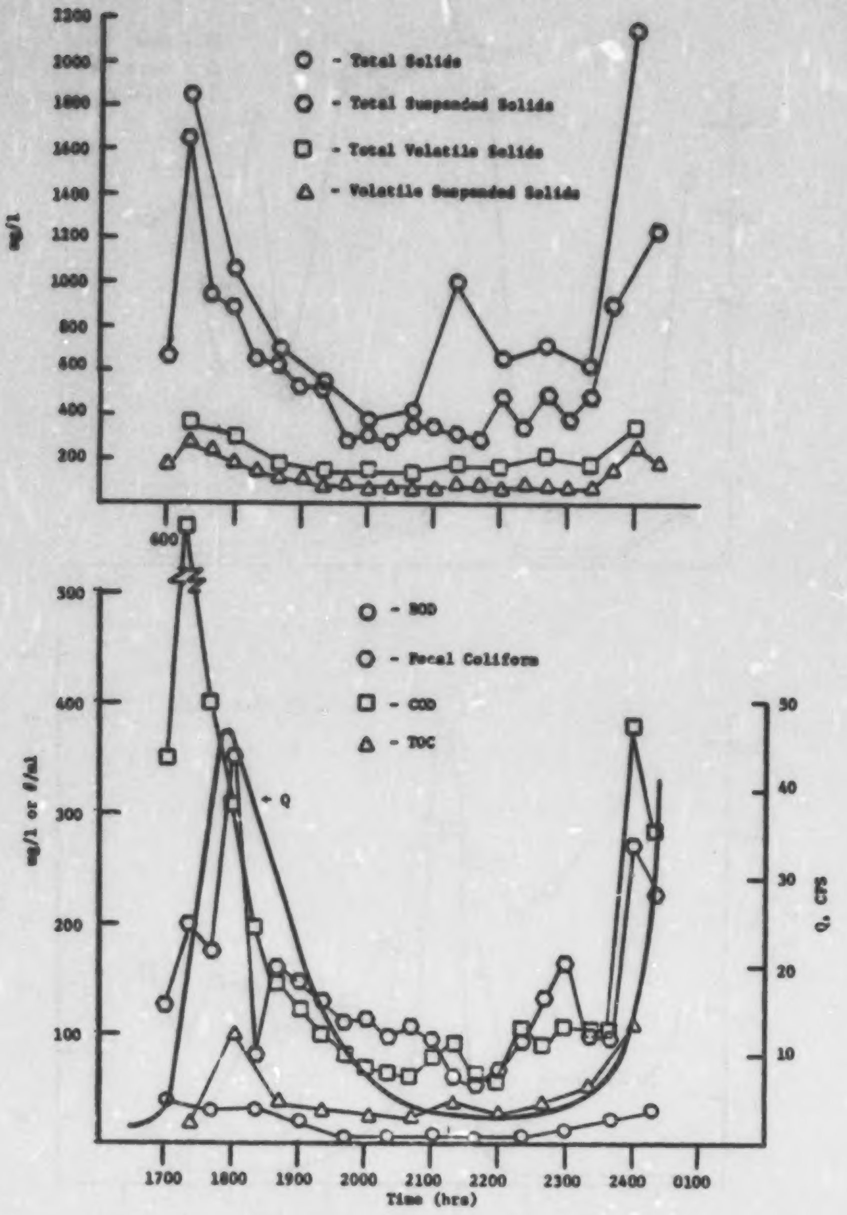


Figure 39. Pollutant variations with Q and time for Storm No. 13, Date 3/16/72.

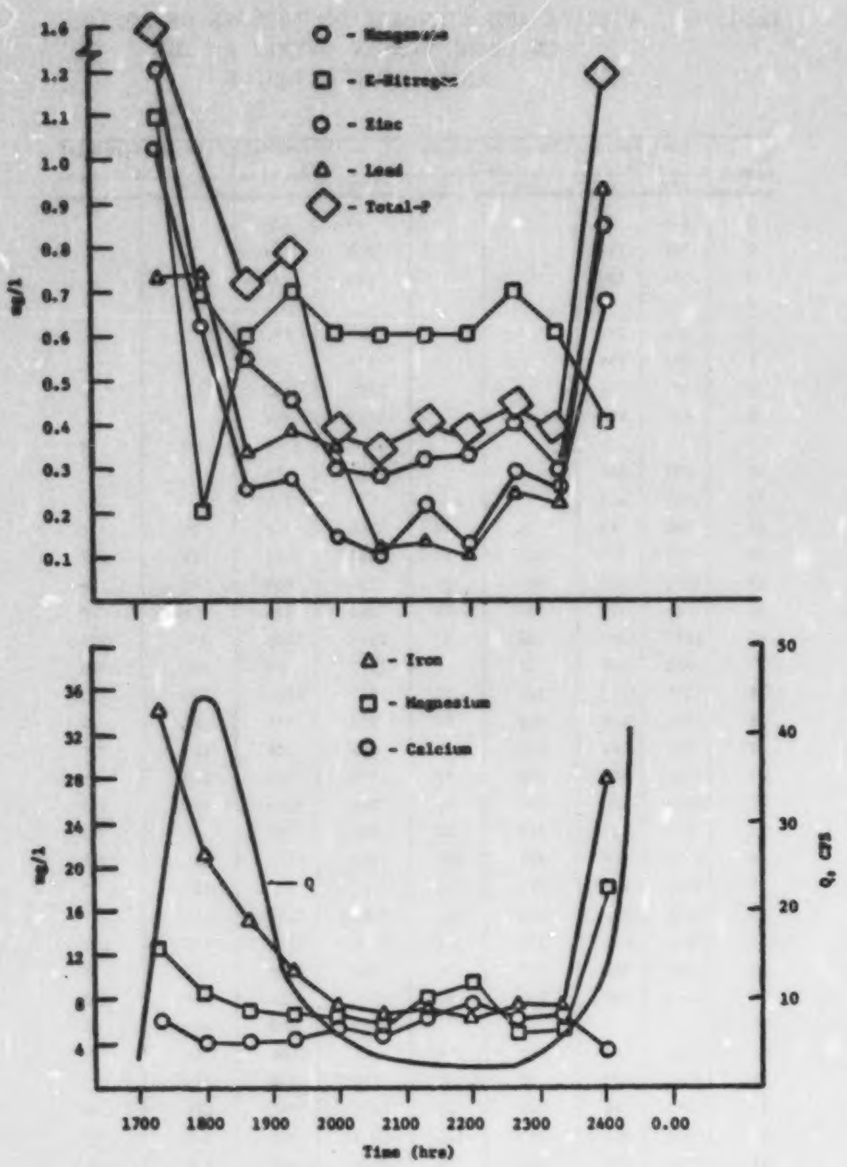


Figure 40. Pollutant variations with Q and time for Storm No. 13, Date 3/16/72.

Table 4. AVERAGE AND STANDARD DEVIATIONS OF SOLIDS IN URBAN RUNOFF EVENTS AT THE MAIN GAGING STATION

Storm Number	Total Solids mg/l		Volatile Solids mg/l		Total Suspended mg/l		Volatile Suspended mg/l	
	Avg	σ	Avg	σ	Avg	σ	Avg	σ
1	226	27			89	38		
2	538	143			274	164		
3	571	180			163	86		
4								
5	520	264			346	272		
6	676	294			474	249		
7	1675	492			1459	535		
8	1423	874			1233	949		
9					1754	1194	75	91
10	982	384			572	421		
11	1169	453			990	733		
12	391	63	78	18	146	58	15	8
13	913	574	215	84	687	472	119	68
14	1124	435	147	39	1087	492	92	36
15	960	412	148	29	843	429	121	40
16	1932	1273	182	65	2596	2107	152	102
17	1583	506	133	44	1525	655	132	208
18	1215	1197	107	17	849	1117	76	15
19	991	426	110	51	899	576	82	74
20	871	324	145	40	895	789	129	101
21	2460	467	288	88	2732	725	240	67
22	3940	2820	500	452	2332	1090	380	395
23	682	319	168	29	554	290	40	27
24	3570	908	485	102	2889	1266	318	129
25	3080	1117	224	123			136	93
26	5423	2597	323	127	3913	2204	152	101
27	3300	3076	283	182	2522	2434	221	149
28	1147	343	147	38	1024	376	71	25
29	1487	664	186	60	1326	624	105	49
30					1340	1100	147	24
31	1050	588	242	56	83	62	14	7
32	1144	913	138	43	777	788	120	53
33	1497	542	260	41	1246	550	145	40
34	1822	941	285	135	1463	923	188	97
35	1234	258	284	45	1029	288	136	10
36	719	152	177	30	643	202	104	17

Table 5. AVERAGE AND STANDARD DEVIATION OF TOTAL PHOSPHORUS, KJELDAHL NITROGEN, AND FECAL COLIFORMS IN URBAN RUNOFF EVENTS AT THE MAIN GAGING STATION

Storm Number	Total P mg/l		K-Nitrogen mg/l		Fecal Coliforms #/ml	
	Avg	σ	Avg	σ	Avg	σ
1	0.28	0.04	0.91	0.09		
2	0.6	0.21				
3	1.03	0.35	*9.52	*4.01	203	148
4	0.47	0.13	*9.68	*3.57	398	184
5	1.05	0.88	1.30	0.17	387	246
6	0.75	0.31	1.94	0.49	689	111
7	1.07	1.05	0.67	0.39	106	88
8	0.58	0.24	0.35	0.31	74	39
9	0.5	0.43	0.56	0.46	54	48
10	0.57	0.26	0.39	0.12	67	28
11	1.05	0.36	0.76	0.30		
12	0.81	0.22	0.65	0.15	102	65
13	1.98	4.65	0.6	0.21	137	71
14						
15						
16	1.03	0.79	0.67	0.58	143	43
17	0.56	0.23	0.44	0.2	161	51
18	0.36	0.29	0.31	0.03	4	2
19	0.62	0.34	0.82	0.12	442	387
20	1.09	0.93	0.88	0.29	98	83
21	1.17	0.55	0.49	0.25		
22	1.13	0.39	0.64	0.33	175	94
23	0.44	0.19	0.25	0.08	280	125
24	1.42	0.37	0.34	0.25	549	363
25	0.73	0.23	0.35	0.11		
26						
27	0.85	0.47	0.48	0.19	172	221
28	0.36	0.07	0.33	0.14	248	65
29	0.71	0.21	2.07	1.28		
30	.71	.24	.43	.13	94	31
31	0.92	0.62	0.34	0.05	273	168
32						
33	0.6	0.18	0.2	0.05	44	21
34	1.54	0.51	0.70	0.13		
35						
36	0.39	0.13	0.48	0.18	258	105

*Questionable values

Table 6. AVERAGE AND STANDARD DEVIATION OF METALS CONCENTRATION IN URBAN RUNOFF EVENTS AT THE MAIN GAGING STATION

Storm Number	Calcium mg/1		Cobalt mg/1		Copper mg/1		Chromium mg/1		Iron mg/1		Lead mg/1		Nickel mg/1		Magnesium mg/1		Manganese mg/1		Zinc mg/1	
	Avg	σ	Avg	σ	Avg	σ	Avg	σ	Avg	σ	Avg	σ	Avg	σ	Avg	σ	Avg	σ	Avg	σ
1			0.36	0.09	0.36	0.10			4.4	1.3									0.27	0.27
2			0.13	0.03	.14	.03	.31	.07	3.5	.8	.49	.11	.16	.04			.59	.10	.19	.04
3			0.08	0.04	0.10	0.03	0.33	0.08	3.8	1.7	0.43	0.07	0.16	0.03			0.71	0.26	0.17	0.08
4			0.14	0.05	0,13	0.03	0.31	0.06	10.6	2.9	0.53	0.09	0.18	0.04			0.60	0.11	0.32	0.08
5	7.0	7.8					0.27	0.03	9.1	4.2	0.57	0.24			11.7	4.7	0.62	0.24	0.31	0.15
6	2.5	0.5							11.2	4.1	0.40	0.14			9.3	2.1	0.63	0.23	0.24	0.10
7	2.7	1.6					0.29	0.09	11.4	4.9	0.42	0.22			9.1	3.5	0.69	0.37	0.34	0.19
8	5.5	7.9					0.27	0.07	9.9	6.3	0.43	0.16			10.6	5.4	0.56	0.26	0.27	0.15
9	4.1	1.3							9.1	4.7	0.35	0.26			8.5	2.2	0.52	0.16	0.68	0.91
10	14.3	14.2							7.8	3.9	0.47	0.30			11.2	3.2	0.64	0.14	0.58	0.29
11	6.2	3.5							16.3	14.5	0.57	0.80			15.2	4.0	0.89	0.44	0.96	0.88
12	24.7	4.9							3.7	1.0	0.26	0.12			9.4	1.6	0.44	0.06	0.21	0.06
13	5.3	1.3							13.6	9.7	0.38	0.29			3.9	.3	0.51	0.29	0.36	0.29
14	4.2	1.4							9.3	3.5	0.29	0.14			8.6	2.4	0.43	0.22	0.25	0.10
15	5.2	3.7							7.7	4.4	0.23	0.15			7.7	1.1	0.33	0.18	0.21	0.11
16					0.15	0.07	0.16	0.09			0.45	0.46							0.30	0.37
17					0.10	0.00	0.11	0.03			0.23	0.17							0.25	0.16
18					0.10	0.00	0.10	0.00			0.10	0.00							0.10	0.01
19			0.1	0.0					12.9	8.3	0.47	0.54	0.1	0.0			1.07	0.76		
20			0.09	0.00					12.1	8.2	0.49	0.38	0.09	0.00			0.95	0.63		
21															13.4	1.4	2.01	0.38	0.83	0.37
22															12.4	1.2	0.71	0.17	0.42	0.06
23															4.7	0.8	0.40	0.25	0,22	0.10
24															11.9	1.6	1.67	0.24	0.53	0.19
25	2.3	0.8			0.14	0.02	0.10	0.04							7.2	2.2			0.34	0.11
26																				
27									32.8	14.6	0.79	0.75					1.32	0.91		
28									19.0	5.6	0.26	0.09					0.60	0.16		
29	2.1	1.3			0.12	0.01	0.15	0.04							12.6	4.4				
30																				
31									18.8	9.3	0.20	0.26							0.33	0.23
32									19.6	9.4	0.28	0.12							0.28	0.14
33					0.12	0.02											0.44	0.08	0.28	0.05
34					0.12	0.02	0.16	0.03			1.19	0.32			15.5	2.5				
35					0.13	0	0.11	0			0.69	0.14								
36											0.24	0.08								

Table 7. AVERAGE, RANGE, AND STANDARD DEVIATION OF POLLUTANT CONCENTRATIONS FOR ALL STORM SAMPLES

Pollutant	Mean mg/1	Standard deviation	Range (mg/1)	
			Low	High
COD	170	135	20	1042
TOC	42	35	5.5	384
Total Solids	1440	1270	194	8620
Volatile Solids	205	124	33	1170
Total Suspended Solids	1223	1213	27	7340
Volatile Suspended Solids	122	100	5	970
Kjeldahl Nitrogen as "N"	.96	1.8	.1	11.6
Total Phosphorus as "P"	.82	1.0	.2	16
Fecal Coliform (#/ml)	230	240	1	2000
Aluminum	16	8.15	6	35.7
Calcium	4.8	5.6	1.1	31
Cobalt	.16	.11	.04	.47
Chromium	.23	.10	.06	.47
Copper	.15	.09	.04	.50
Iron	12	9.1	1.3	58.7
Lead	.46	.38	0.1	2.86
Magnesium	10	4.0	3.6	24
Manganese	.67	.42	.12	3.2
Nickel	.15	.05	.09	.29
Zinc	.36	.37	.09	4.6
Alkalinity	56	30	24	124

Table 8. AVERAGE BASE FLOW POLLUTANT CONCENTRATION FOR SUB-BASINS AND MAIN GAGING STATION

Sub-basin		E-1	E-2	N-2	W-1	W-2	Total basin
Dissolved oxygen (mg/1)		8.8	9.7	7.5	8.8	9.9	8.4
Organics (mg/1) -	COD	21	24	81	22	28	29
	TOC	17	13	29	15	17	14
	BOD_5	10	10	25	8	18	15
Solids (mg/1) -	TS	358	392	428	250	289	400
	TVS	98	107	101	81	85	90
	SS	82	20	25	20	24	50
	VSS	14	16	18	11	16	25
Nutrients (mg/1)-	K-N	1.0	1.0	1.4	1.5	2.6	2.2
	Total-P	.1	.2	1.8	.3	.7	.6
Fecal Coliform (#/ml)		8	30	50	120	70	50
Metals (mg/1) -	Ca	45	45	21	29	30	26
	Co	.10	.15	.10	.13	.17	.26
	Cr	.25	.21	.30	.23	.26	.23
	Cu	.10	.16	.14	.11	.14	.27
	Fe	2.3	1.4	1.4	1.2	2.8	1.5
	Mg	13.4	17.7	11.2	11.4	12.4	11.8
	Mn	1.3	.50	.47	.42	.40	.52
	Ni	.19	.15	.17	.19	.20	.16
	Pb	.27	.24	.21	.18	.19	.26
	Zn	.13	.15	.51		.11	.16

The average pollutant concentration for individual storms for each sub-basin and the main gaging station are presented in Table 9. The raw data on each sub-basin storm sample is in Appendix C. As evidenced by Table 9, there is not much quality variation in the discharges from individual sub-basins. The main gaging station, which represents the entire basin, does exhibit greater concentrations of COD and solids, assumed to be caused by the difference in sampling techniques. The sub-basins were manually sampled, whereas the main gaging station was sampled automatically.

It was concluded that the individual sub-basins within the Third Fork Creek urban drainage basin do not exhibit significant variations in urban runoff water quality to indicate any influence of land use on quality of urban runoff.

Table 9. AVERAGE POLLUTANT CONCENTRATIONS FROM SUB-BASINS DURING STORM FLOWS

Sub-basin		E-1	E-2	N-2	W-1	W-2	Total basin
Organics (mg/1) -	COD	93	130	102	95	101	170
	TOC	30	32	30	35	32	42
	BOD_5	60	69	83	36	81	
Nutrients (mg/1)-	K-N	.36	.44	.57	.42	.31	.96
	Total-P	.50	.53	.59	.54	.57	.82
Fecal Coliforms (#/ml)		540	185	50	242	265	230
Solids (mg/1) -	Total	834	849	977	819	938	1440
	TVS	202	156	133	132	134	205
	SS	627	638	770	629	739	1223
	VSS	102	80	99	87	142	122
Metals (mg/1) -	Al	27	23	22	18	23	16
	Ca	2.2	4.1	1.6	1.8	2.0	4.8
	Co	<.1	.1	<.1	<.1	<.1	.16
	Cr	.13	.15	.16	.13	.15	.23
	Cu	.11	.13	.12	.10	.12	.15
	Fe	10	6	5	10	13	12
	Mg	16	10	10	7.5	11	10
	Mn	.84	.49	.51	1.1	.52	.67
	Ni	<.1	<.1	<.1	<.1	<.1	.15
	Pb	.26	.13	.32	.27	.25	.46
	Sr	<.1	<.1	<.1	<.1	.11	
	Zn	.22	.32	.27	.32	.23	.36

BOD Difficulties

The Biochemical Oxygen Demand (BOD) test is, and has been, the prime tool of engineers and chemists in estimating the amount of potentially biodegradable material present in a waste and the rate at which oxygen will be utilized in a receiving watercourse. Test usage is so widespread and results so universally accepted that it is sacrilegious to question its applicability and usefulness. However, during the project's course, it became apparent that BOD was an inappropriate analytical test for organic characterization of urban land runoff.

All BOD analyses were run in accordance with Standard Methods (8). Samples were not "seeded." Doubly distilled dilution water was initially used; and later, singly distilled deionized dilution water was utilized. All tests were conducted at 20°C with a water seal.

The major difficulty encountered with the BOD test was that results were affected by the percent stormwater of the sample. Percent stormwater is defined as 100 times the volume of stormwater divided by the total volume of liquid. The more dilute the sample, the greater the BOD exerted as shown in Figures 41 and 42 which present typical variations of BOD as a function of percent dilution. It is important to note that generally the dissolved oxygen depletion was approximately the same in all dilutions. Consequently, BOD values appear inversely proportional to the percent stormwater (i.e., at concentrations of 1 and 2 percent, the BOD of the 1 percent concentration is approximately twice that of the 2 percent stormwater concentration). As different concentrations exhibited more or less the same oxygen depletion, in mg/l, the problem continuously arose as to which value was the "true" value and should be reported as representing or indicating the strength of urban land runoff. If three different concentrations met the requirements of a minimum residual dissolved oxygen concentration of 1 mg/l and a depletion of at least 2 mg/l, the results of the median concentration was reported.

During the first portion of the project, concentrations of 10 and 15 percent were commonly used for 5-day BOD's. These low concentrations produced low BOD values as compared to COD and TOC. During the remainder of the project, 0.5 percent, 1 percent, and 2 percent concentrations were commonly used for BOD's, and the relative value of BOD's as compared with COD and TOC were higher. This can be seen in Table 3, giving the mean and standard deviation of organics for the 36 storms sampled. Storm Nos. 1 through 19 were run at the lower concentrations while 20 through 36 were run at the higher dilutions.

The exact cause for the difficulties experienced with the BOD test as applied to urban land runoff is not known. However, the phenomena could be due to (1) the inhibitory effect of heavy metals, (2) the presence of other unidentified inhibitory compounds, and/or (3) inherent problems of the standard BOD test.

Therefore, it is recommended that BOD not be considered an appropriate or representative measure of pollutant strength of urban land runoff. The BOD values presented within this report are not considered valid and should only be utilized to assess the magnitude of problems of associating BOD with urban land runoff. The only reason for presenting BOD values is that they were specified as part of the work to be performed under the contract and that all information gathered would be fully reported and disclosed.

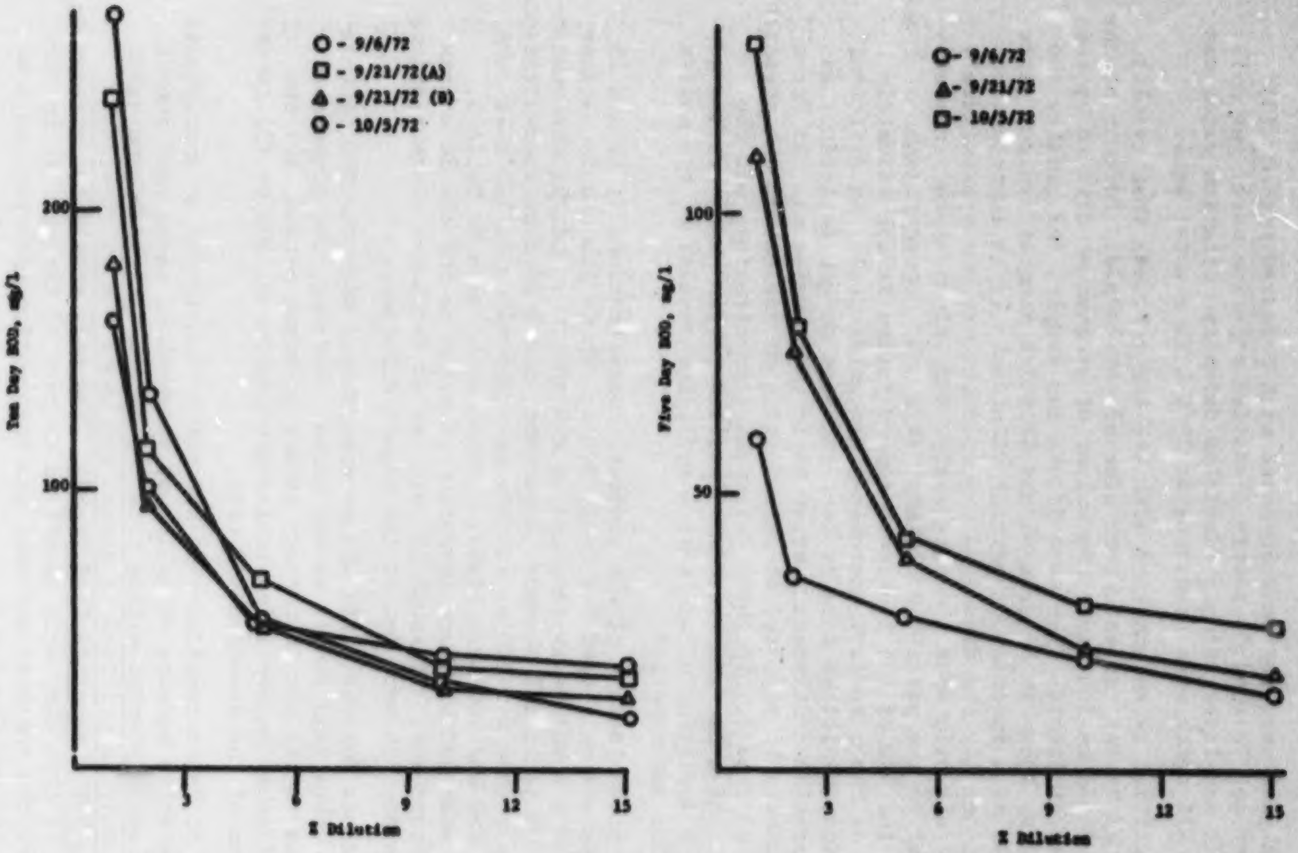


Figure 41. Typical variations of BOD with dilution.

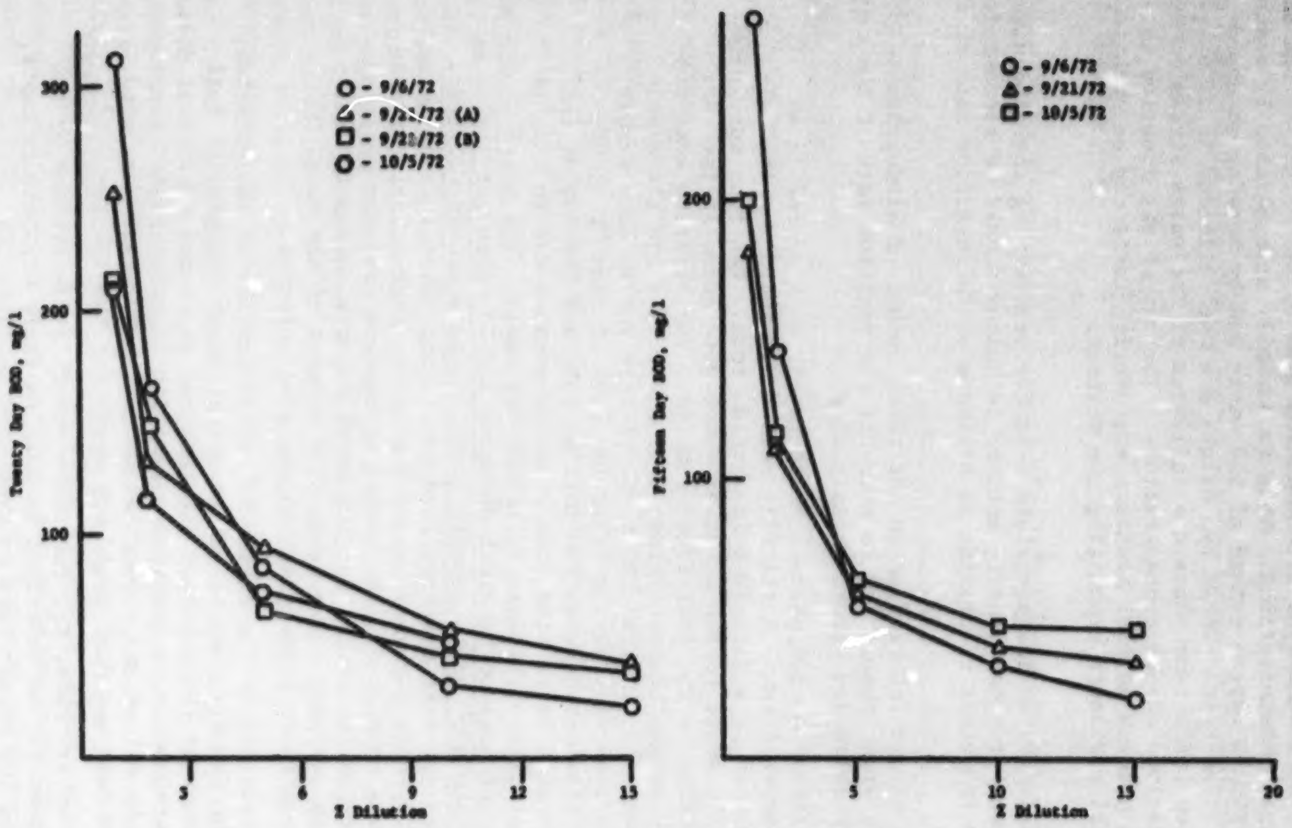


Figure 42. Typical variations of BOD with dilution.

COD Exertion Rate Studies

An important aspect of the project was to assess the impact of the urban land runoff on a receiving stream as measured by its effect on the dissolved oxygen concentrations. This is normally accomplished by assessing the ultimate oxygen demand of the waste and by knowing an appropriate exertion rate. These two values are then utilized in an oxygen sag equation which represents the influence of the waste stream on downstream dissolved oxygen concentrations. The oxygen sag equation is a relationship found in most sanitary engineering texts and as such is known by all engineers practicing the science.

As BOD was judged an inappropriate test for determining the ultimate oxygen demand of urban runoff, another technique should be recommended. It is also important to provide an estimate of the exertion rate of the new test.

To provide needed information on the total amount of biodegradable material in urban runoff and to evaluate the exertion rate of the oxygen demand, the following study was initiated:

> Four liters of 100 percent urban runoff were placed in an erlenmeyer flask. A stirring magnet was added and the bottle placed in a dark 20°C incubation room. The four nutrients normally added to BOD dilution water were added in the same proportion to the four-liter samples. The stirring kept dissolved oxygen concentrations near saturation and the sample homogeneous. Initial COD's (COD_I) were run on each sample and periodically during following days at time "t" (COD_T). The difference between the initial COD_I and the COD of the sample at a later time (COD_T) can be assumed due to biological activity or biodegradation of the waste. The total amount of organic material degraded should represent the "ultimate BOD" as supposedly given by the standard BOD test. The COD jar test was continued until that point in time when the COD_I-COD_T became constant indicating that all biodegradation was completed. The method of moments commonly employed for evaluation of K_1, the BOD exertion rate constant, was used to evaluate COD uptake. The percent of the total COD susceptible to biodegradation was also computed.

The biodegradation in the flasks is still subject to inhibitation; however, the COD test can be run at any strength (hopefully, full strength) whereas the standard BOD test has to be run at several dilutions. Consequently, a standard evaluation of urban runoff degradation rate could be set at any concentration if the COD test were used, whereas the same standard could not apply for the BOD test.

The oxygen uptake rate, K_1, for urban runoff as determined by the method of moments, as described in most sanitary engineering texts, from BOD and COD uptake data is presented in Table 10.

Table 10. OXYGEN UPTAKE RATES (K_1) FOR URBAN LAND RUNOFF

Sample	Test	Stormwater concentration (%)	Rate** K_1	Ultimate uptake mg/1	Percent* biodegradable
Urban Runoff	COD	100	.08	106	44
	BOD	.5	.07	540	
	BOD	1.0	.13	190	
Secondary Sewage	COD	100	.14	48	53
	BOD	1	.20	125	
	BOD	5	.10	55	
Urban Runoff	COD	100	.20	98	53
	BOD	1	.27	137	
	BOD	5	.27	112	
	BOD	5	.24	124	
Urban Runoff	COD	100	.06	20	16
	BOD	2	.16	47	
	BOD	5	.20	30	
Urban Runoff	COD	100	.13	57	61

* Biodegradable COD ÷ Total Initial COD

** Base e

One sample of secondary effluent from a municipal waste plant prior to chlorination is also included in the table for comparison. All K_1 rates are based solely on either BOD or COD uptake rates through 20 days, although biodegradation in the 4-liter COD flasks continued well beyond 20 days. Figure 43 compares oxygen exertion curves as determined by BOD and COD uptake.

The COD K_1 rates for urban runoff vary from .06 to 0.20 per day while K_1, as determined by the conventional BOD test, varies from 0.08 to 0.27. The K_1 rates as determined by both techniques compare favorably for the same sample indicating either could be used. The ultimate amount of biodegradable material, however, appears to be dependent upon the percent dilution. The ultimate oxygen demand in 20 days as determined from the COD tests for the 100 percent sample is always less than that predicted by the BOD test. It appears that K_1 is independent of sample dilution or analysis technique whereas the 20-day ultimate oxygen demand is dependent on sample dilution.

The rather large range in the oxygen uptake rate as predicted by either technique is somewhat of a problem when used with an oxygen sag equation, as the sag characteristics are significantly influenced by K_1. Oxygen uptake rates are certainly influenced by sample characteristics which, as previously shown, vary considerably for urban land runoff. The precise inhibitory effect of heavy metals on uptake rates is unknown. During urban runoff events, the relative quantity of urban runoff in Third Fork Creek was 10 to 1700 times as great as base flow. Consequently, minimal base flow dilution was available for organics

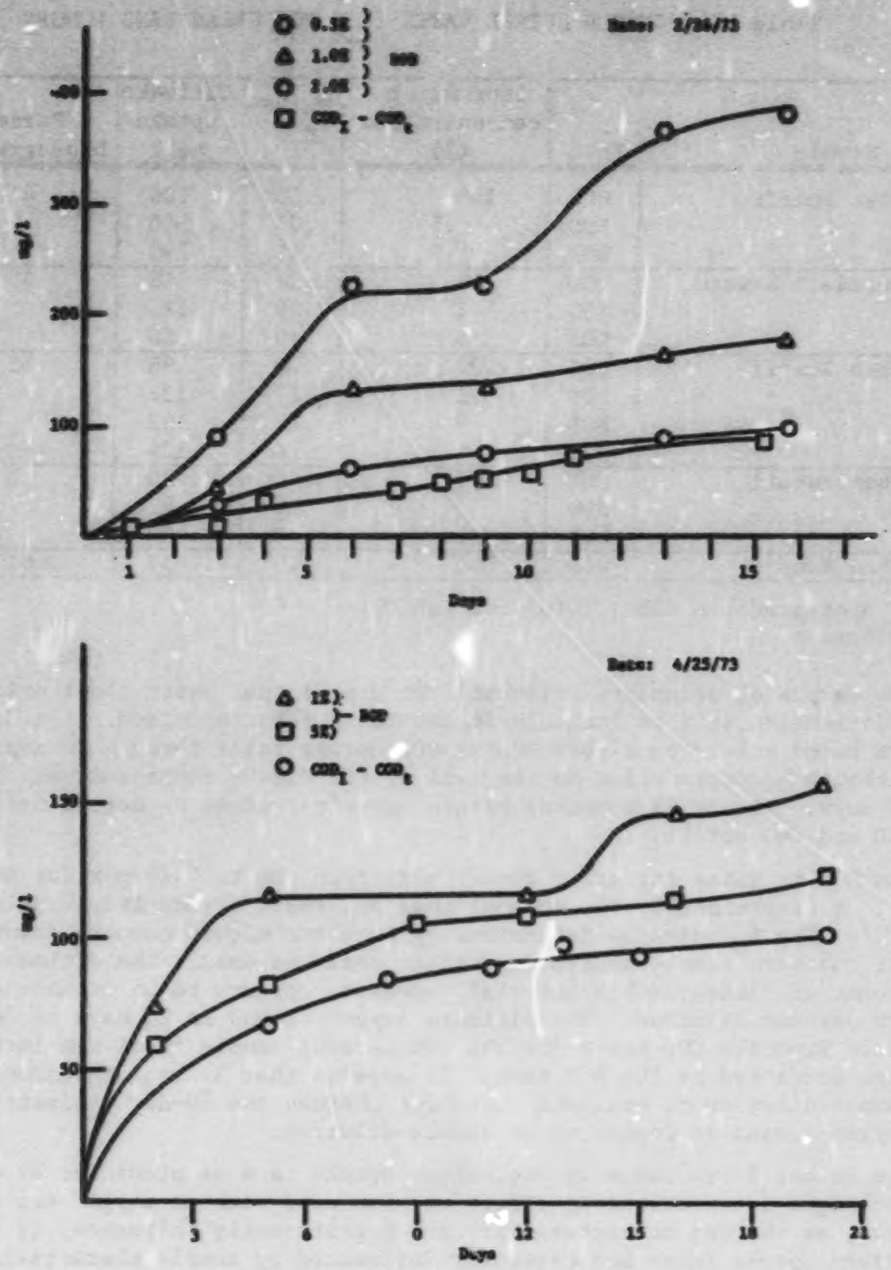


Figure 43. Oxygen exertion curves as determined by BOD and COD uptake.

and heavy metals. The COD uptake rate technique does allow for K_1 evaluation at greater concentrations than does the typical BOD test.

The percent of COD capable of biodegradation in 20 days was found to vary from 16 to 61 percent with an average of 44 percent.

From these studies it was concluded that (1) approximately 40 to 50 percent of the COD load contributed by urban runoff is susceptible to biodegradation in 20 days, (2) that the COD K_1 exertion rate is equivalent to that obtained by a conventional BOD test, (3) that the standard BOD test is not an appropriate test for evaluation of urban land runoff, and (4) that the COD test gives a reproducible value at 100% of sample strength.

Representative Sampling

The automatic sampling device located at the USGS gaging station was powered by a submersible centrifugal pump as previously described in the sampling section. The pump, positioned in a perforated box, was located approximately three feet downstream of the weir on the bottom of the stream channel. Consequently, during runoff events the samples taken were from the lower portion of flow in the stream. The question arose as to the representativeness of the samples procured in relation to the average "true" concentration of pollutants at any given time. The velocity profile in a natural channel is well known; and consequently, pollutant concentration variations should be expected. In an attempt to define the magnitude of the pollutant variations within the cross-sectional flow, samples were obtained manually at the surface of the stream during three separate storms at the same time the automatic sampler was procuring its sample.

The average pollutant concentration at just below the water's surface is compared with the average pollutant concentration of the corresponding samples obtained by the automatic sampler in Table 11. As can be seen in the table, the concentrations of pollutants were almost always greater for samples obtained automatically adjacent to the bottom than they were at the surface. The COD concentration adjacent to the surface is 67 percent of that obtained at the bottom. It is apparent that at least two important profiles exist in Third Fork Creek, a velocity profile and a pollutant profile.

Pollutant Regression Equations

In order to describe pollutant concentration variations within storms and to assess the annual pollutant yield of urban runoff, analytical data from the 36 storms sampled were used to determine appropriate regression equations relating yield to runoff characteristics. The independent variables used were rate of runoff (CFS), time from storm start (TFSS) in hours, time from last storm (TFLS) in hours, and time from last peak (TFLP) in hours.

Initially, all four independent variables were used for regression to determine which were significant in describing pollutant yield

Table 11. COMPARISON OF POLLUTANT CONCENTRATIONS ADJACENT TO WATER'S SURFACE WITH THOSE OBTAINED BY AUTOMATIC SAMPLER

Pollutant	Surface concentration	Automatic sampler concentration	Surface concentration as a % of automatic sampler concentration
COD	150	233	67
TOC	40	53	75
BOD_5	62	62	100
K-Nitrogen	.4	.4	100
Total Phosphorus	.78	.90	87
Fecal Coliform (#/ml)	348	427	81
Total Solids	1413	2976	47
Volatile Solids	269	321	84
Total Sus. Solids	1156	2611	44
Volatile Sus. Solids	142	211	67
Calcium	1.76	1.69	104
Chromium	.15	.18	83
Iron	10.7	14.8	72
Magnesium	8.8	9.8	90
Manganese	.81	1.11	73
Lead	.24	.31	77
Zinc	.34	.45	76

variations within storm events. As a result, it was found that the rate of discharge (CFS) and time from storm start (TFSS), as indicated by runoff initiation, in hours were the two most significant variables. Only a modest gain in the correlation coefficient, r^2, was realized with the additional two time variables. It was decided to limit the regression equations to CFS and TFSS for regression simplicity.

Prior opinion would indicate that TFLS should be a significant factor, the more frequent runoff events are the less the buildup time for pollutants on an urban watershed. However, for the Third Fork Creek in Durham, North Carolina, the frequency of runoff events did not appear to influence significantly the pollutant discharge from the basin.

The final regression equations describing urban runoff pollutant flow in pounds per minute as a function of CFS and TFSS are presented in Table 12 with the corresponding correlation coefficients.

The COD values for Storm Nos. 1 and 2 were excluded from the analysis as the samples were obtained manually instead of by the automatic sampler. The kjeldahl nitrogen values for Storm Nos. 3 and 4 were excluded as the results were considered atypical.

The regression equations as presented in Table 12 can be adjusted to produce equations relating pollutant concentration in mg/l to rate of flow and time from storm start. The regression equations may also be adjusted to reflect concentrations at mid-depth. The equation relating COD in pounds per minute as a function of CFS and TFSS is:

Table 12. EQUATIONS DESCRIBING URBAN RUNOFF POLLUTANT FLUX NEAR CHANNEL BOTTOM IN POUNDS PER MINUTE FOR DURHAM, NORTH CAROLINA, AS A FUNCTION OF DISCHARGE RATE (CFS) AND TIME FROM STORM START (TFSS) IN HOURS

Equation	R^2
COD = 0.51 $\text{CFS}^{1.11}$ $\text{TFSS}^{-.28}$	.90
TOC = 0.16 $\text{CFS}^{1.0}$ $\text{TFSS}^{-.28}$	.84
Total Solids = 3.35 $\text{CFS}^{1.14}$ $\text{TFSS}^{-.18}$	.85
Volatile Solids = 0.58 $\text{CFS}^{1.09}$ $\text{TFSS}^{-.11}$	.92
Suspended Solids = 1.89 $\text{CFS}^{1.23}$ $\text{TFSS}^{-.16}$	.76
Volatile Suspended Solids = 0.25 $\text{CFS}^{1.18}$ $\text{TFSS}^{-.17}$	.83
Kjeldahl Nitrogen = 0.0032 $\text{CFS}^{.87}$ $\text{TFSS}^{-.29}$	.73
Total Phosphorus as P = 0.003 $\text{CFS}^{1.03}$ $\text{TFSS}^{-.29}$	.92
Aluminum = 0.0443 $\text{CFS}^{1.05}$ $\text{TFSS}^{-.15}$	.89
Calcium = 0.045 $\text{CFS}^{0.60}$ $\text{TFSS}^{-.09}$	.82
Cobalt = 0.0003 $\text{CFS}^{1.18}$ $\text{TFSS}^{+.13}$	.92
Chromium = 0.0008 $\text{CFS}^{.96}$ $\text{TFSS}^{+0.06}$	.89
Copper = 0.00035 $\text{CFS}^{1.10}$ $\text{TFSS}^{+.08}$	.94
Iron = 0.0238 $\text{CFS}^{1.24}$ $\text{TFSS}^{-.18}$	.87
Lead = 0.0013 $\text{CFS}^{1.125}$ $\text{TFSS}^{-.29}$	.83
Magnesium = 0.0434 $\text{CFS}^{.98}$ $\text{TFSS}^{-.16}$	.94
Manganese = 0.0023 $\text{CFS}^{1.11}$ $\text{TFSS}^{-.27}$	.94
Nickel = 0.0005 $\text{CFS}^{1.03}$ $\text{TFSS}^{+.01}$	.94
Zinc = 0.0011 $\text{CFS}^{1.10}$ $\text{TFSS}^{-.22}$	.89

$$COD = 0.51\ CFS^{1.11}\ TFSS^{-0.28}$$

where COD is in pounds per minute

CFS is cubic feet per second

and TFSS is time in hours from the initiation of runoff.

The equation may be adjusted to reflect concentrations at average depth with the use of a correction factor derived from information contained in Table 11. The correction factor for COD is 0.835; i.e., (1 + .67) ÷ 2. This yields the equation:

$$COD = .425\ CFS^{1.11}\ TFSS^{-.28}$$

To modify the COD equation to reflect mg/l COD as a function of CFS and TFSS, the relationship is:

$$mg/l = \frac{267\ lbs/min}{CFS}$$

The regression equation, therefore, becomes:

$$COD = 113\ CFS^{0.11}\ TFSS^{-.28}$$

where COD is in mg/l at average depth.

All regression equations in Table 12 may be adjusted accordingly to give pollutant concentration in mg/l in a natural channel at mid-depth flow and are as presented in Table 13.

Figures 44 through 46 present variations in pollutant concentrations as a function of CFS and TFSS as predicted by adjusted regression equations for a typical storm hydrograph.

Annual Pollutant Yield

Data from each runoff event occurring during the 1972 calendar year were obtained from the discharge records of the Third Fork Creek gaging station. For each of the 66 storms occurring during the year discharge rates were determined at 30-minute intervals. These rates and the time from storm start were used to find the pollutant yield in pounds per acre per year as a result of urban runoff.

The annual pollutant yield of urban runoff is composed of pollutants contributed during base flow periods and storm periods. As illustrated in Table 11, the average pollutant concentration taken by the automatic sampler was in most cases higher than the corresponding concentrations at the water's surface. Consequently, the total pounds predicted by the regression equations based on data from the automatic sampler are adjusted to reflect the concentrations at mid-depth, assuming a linear

Table 13. REGRESSION EQUATIONS PREDICTING POLLUTANT CONCENTRATION (MG/L) IN URBAN LAND RUNOFF IN A NATURAL CHANNEL CORRECTED TO FLOW AT MID-DEPTH*

Pollutant	mg/l
COD	$113.\ CFS^{0.11}\ TFSS^{-0.28}$
TOC	$32.\ CFS^{0.0}\ TFSS^{-.28}$
TS	$420.\ CFS^{0.14}\ TFSS^{-.18}$
TVS	$130.\ CFS^{0.09}\ TFSS^{-.11}$
TSS	$222.\ CFS^{0.23}\ TFSS^{-.16}$
VSS	$44.\ CFS^{0.18}\ TFSS^{-.17}$
Kjel. N.	$0.85\ CFS^{0.87}\ TFSS^{-.29}$
Total P.	$0.80\ CFS^{0.03}\ TFSS^{-.29}$
Al**	$10.\ CFS^{0.05}\ TFSS^{-.15}$
Ca	$12.5\ CFS^{-.4}\ TFSS^{-.09}$
Co**	$0.07\ CFS^{0.18}\ TFSS^{+.13}$
Cr	$0.18\ CFS^{-.04}\ TFSS^{+.06}$
Cu**	$0.08\ CFS^{0.10}\ TFSS^{+.08}$
Fe	$4.6\ CFS^{0.24}\ TFSS^{-.18}$
Pb	$0.27\ CFS^{0.125}\ TFSS^{-.29}$
Mg	$10.\ CFS^{-.02}\ TFSS^{-.16}$
Mn	$0.45\ CFS^{0.11}\ TFSS^{-.27}$
Ni**	$0.12\ CFS^{0.03}\ TFSS^{-.01}$
Zn	$0.22\ CFS^{0.10}\ TFSS^{-.22}$

* CFS = Cubic Feet Per Second
* TFSS = Time from Storm Start (Hours)
**Mid-depth Correction Assumed as 0.9.

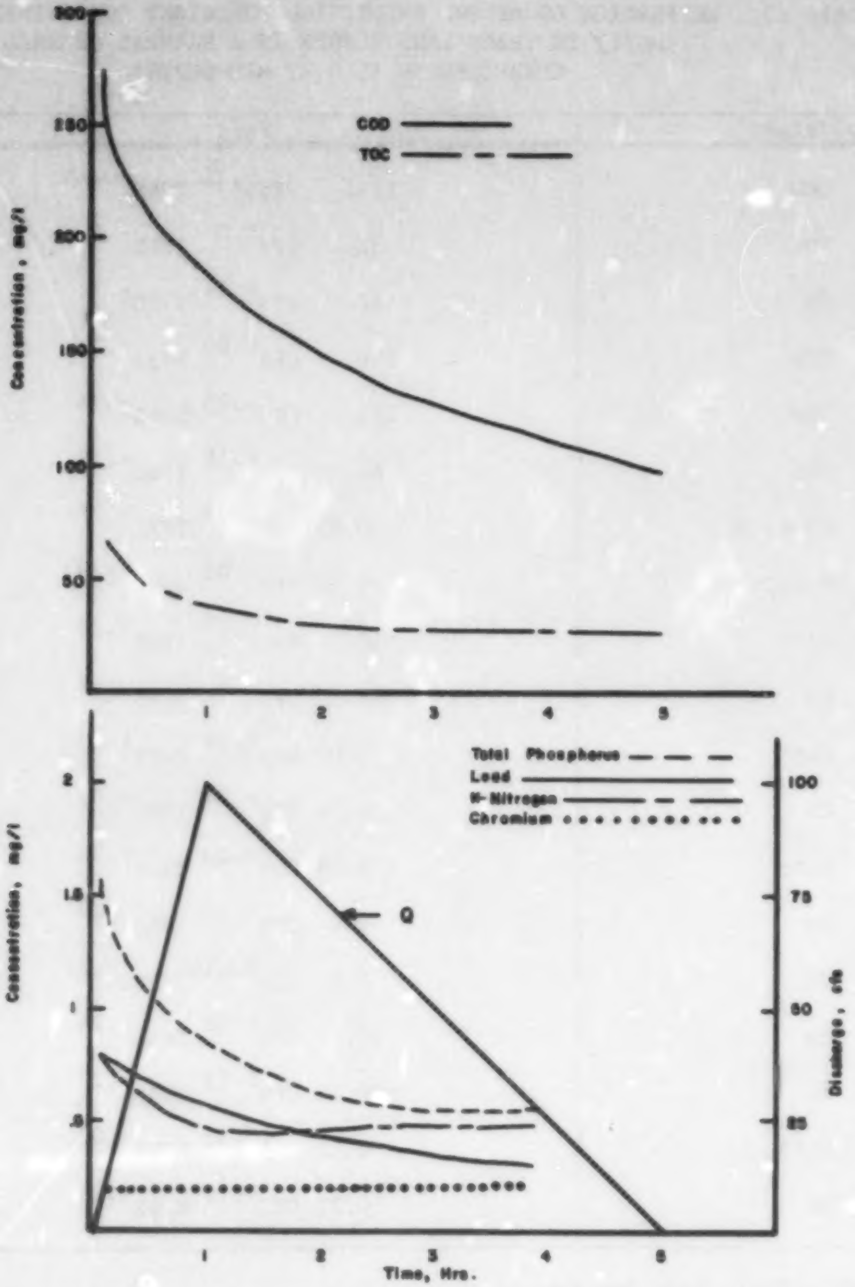


Figure 44. Pollutant concentrations in mg/l for a typical storm hydrograph as predicted by adjusted regression equations.

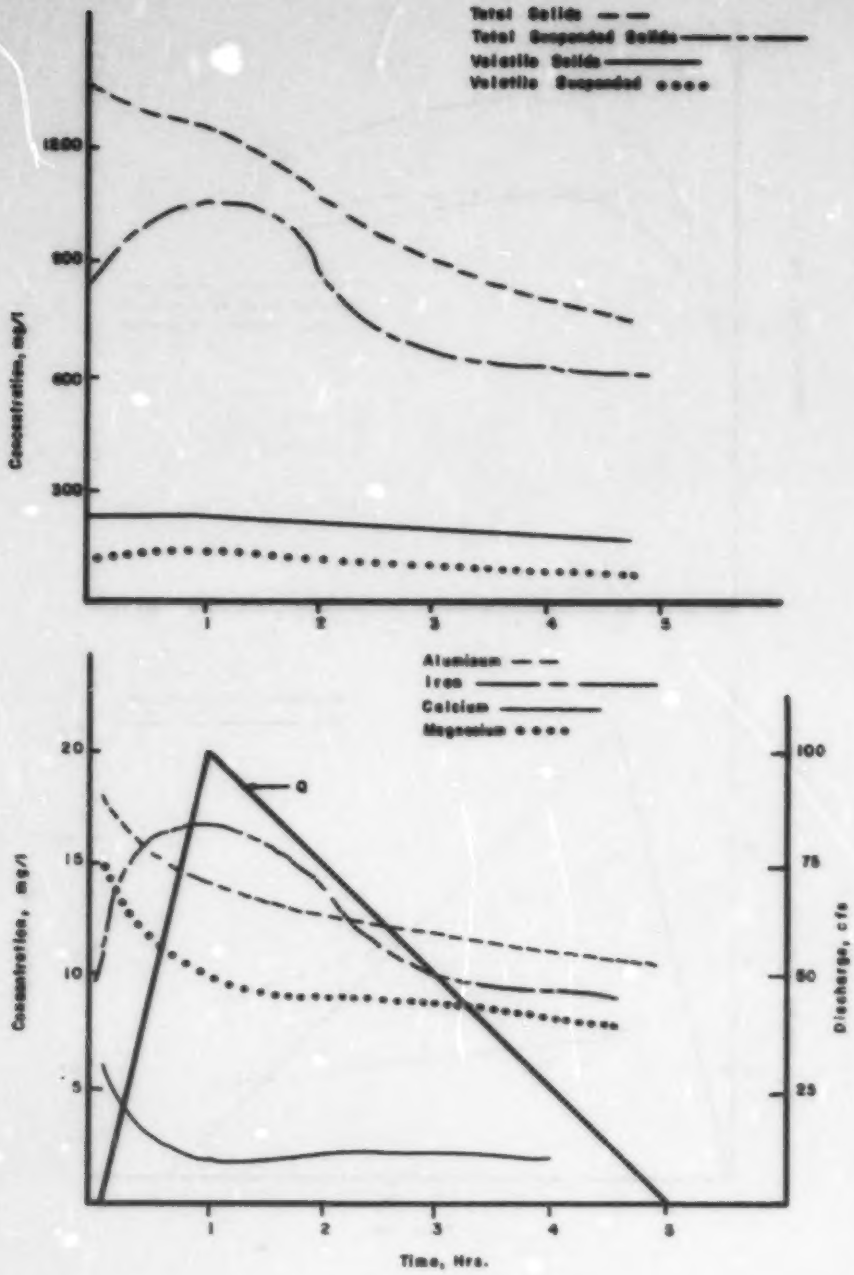


Figure 45. Pollutant concentrations in mg/l for a typical storm hydrograph as predicted by adjusted regression equations.

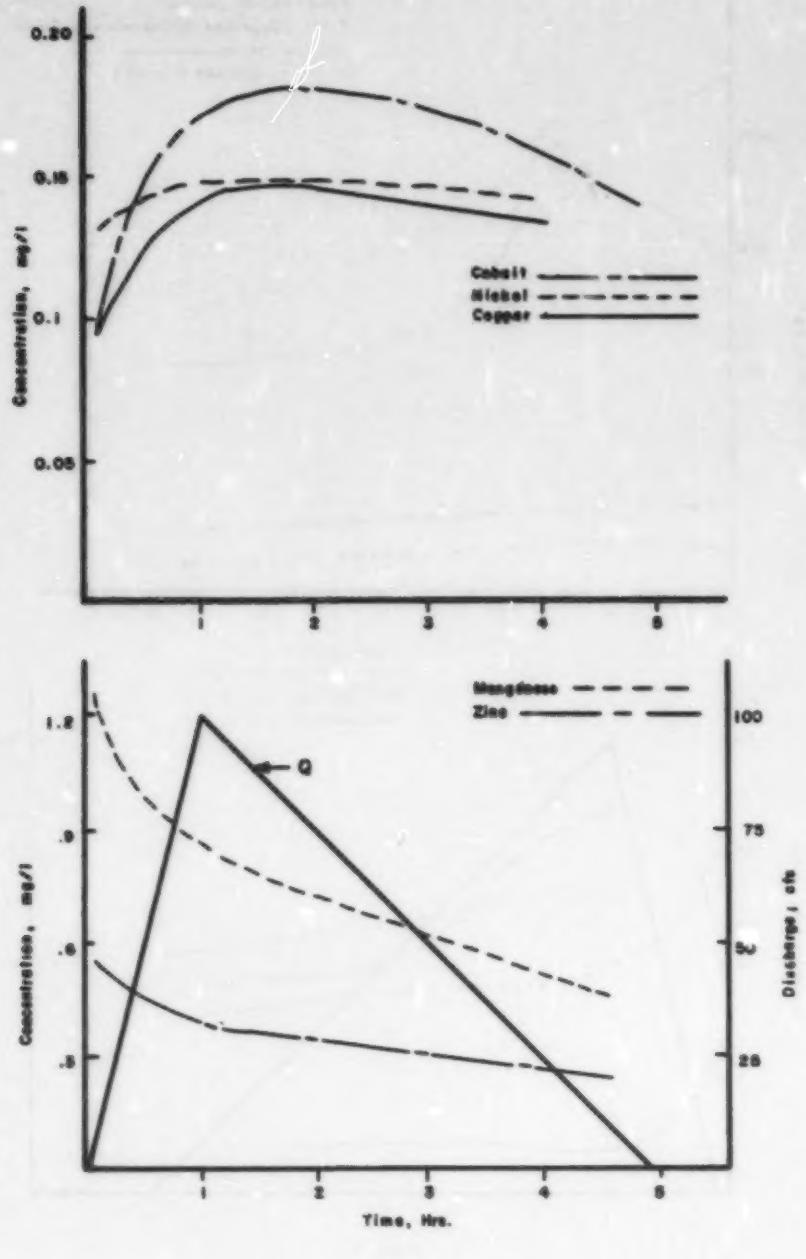


Figure 46. Pollutant concentrations in mg/l for a typical storm hydrograph as predicted by adjusted regression equations.

vertical distribution. The average COD at the surface was 67 percent of that at the bottom. Therefore, a more correct estimate of the pollutant yield assuming a linear variation would be 83.5 percent [(100 + 67) ÷ 2] of that predicted by the regression equations. The annual yield of pollutants from urban runoff in pounds/acre/year for the urban Third Fork study area is presented in Table 14. During the 1972 calendar year, base flow existed 7080 hours or 81 percent of the time, while runoff from the 66 storms required 1680 hours or 19 percent of the time.

Table 14. ESTIMATED 1972 POLLUTANT YIELD FOR THIRD FORK CREEK DRAINAGE BASIN IN POUNDS/ACRE/YEAR

	Urban Runoff				
Pollutant	Predicted	Correction factor	Adjusted yield	Base flow	Annual yield*
COD	1071	.835	895	43	938
TOC	190	.875	166	21	187
Total Solids	9660	.735	7100	600	7700
Volatile Solids	1440	.92	1324	134	1458
Suspended Solids	9190	.72	6617	74	6691
Volatile Sus. Solids	910	.835	760	37	797
Kjeldahl Nitrogen as "N"	2.8	1.0	2.8	3.3	6.1
Total Phosphorus as "P"	4.1	.935	3.8	.9	4.7
Aluminum	76	.90**	63	1.5	64
Calcium	14	1.02	14	38	52
Cobalt	1.7	.90**	1.5	0.4	1.9
Chromium	1.4	.915	1.3	.3	1.6
Copper	1.3	.90**	1.2	.4	1.6
Iron	118	.86	100	2.2	102
Magnesium	57	.95	54	17	71
Manganese	4.9	.865	4.2	.7	4.9
Nickel	1.1	.90**	1.0	.2	1.2
Lead	2.8	.885	2.5	.4	2.9
Zinc	2.1	.88	1.8	.2	2.0

* Annual Yield = Base Flow + Adjusted Yield

** Correction Factor Estimated

Summary

The objective of this portion of the project was the characterization of urban land runoff in Durham, North Carolina, with emphasis on correlation of stormwater quality variations with respect to the rate of flow, storm characteristics, runoff time, and land use.

Thirty-six storms were sampled during the project period through the use of an automatic sampler. Pollutant concentrations were found to vary significantly throughout runoff events and from storm to storm. For most pollutants the standard deviation was approximately 70 to 80 percent of the mean. Pollutant concentrations during the rising limb of the hydrograph were typically higher than those during the remaining hydrograph, indicating a first-flush effect.

Five times during the study storms were manually sampled at sub-basin discharge locations to determine the effect of varying land-use qualities with the quality of urban land runoff. The mean pollutant concentrations from each of the sub-basins were approximately equal, thus indicating little relationship between land use and urban land runoff quality in Durham, North Carolina.

Difficulties with the standard Biochemical Oxygen Demand (BOD) test during the project period led to the conclusion that it was not an appropriate test for evaluation of the organic concentration of urban land runoff.

A technique utilizing the uptake of Chemical Oxygen Demand (COD) to estimate the ultimate amount of organic material susceptible to biodegradation in 20 days indicated that approximately 40 to 50 percent of the COD was capable of biodegradation.

The K_1 (base e) oxygen demand rate for urban land runoff was found to vary from .06 to 0.27 per day, indicating the demand rate is approximately the same as the effluent from a secondary treatment plant.

Substantial pollutant concentration variations were found to exist vertically in the stream channel during runoff events with higher concentrations increasing with depth.

Regression equations were developed for each pollutant relating pollutant flux in pounds/minute as a function of the rate of discharge and lapse of time as measured from the start of the rising limb of the runoff hydrograph. The time since the last storm was not found to be a significant factor affecting the quality of urban land runoff in Durham, North Carolina. These equations may be adjusted to reflect pollutant concentrations in mg/l and to reflect concentrations at mid-depth.

The annual pollutant yield in pounds per acre of drainage basin during the 1972 year was calculated from the 66 storms occurring during the year. The regression equations were utilized with an appropriate factor to correct for vertical variations of pollutant concentrations with depth of flow.

SECTION VII

CHEMICAL-PHYSICAL TREATMENT STUDIES

Introduction

One aspect of the project was investigation and evaluation of the applicability, effectiveness, and economics of physical-chemical treatment of urban runoff by coagulation and sedimentation.

The flow rate variations of urban runoff are substantially different from the flow rate variations encountered at sewage treatment plants. Urban stormwater is an intermittent source of large flows whereas municipal waste is typified by continuous discharge at a relatively constant rate. A widely varying intermittent input is not conducive to effective biological treatment because micro-organisms require continuous feeding with minor variations in input quantity. It appears that a physical and/or chemical removal process for treatment of urban runoff is the most appropriate.

Once it is established that urban runoff should be treated in a given area, the next step is evaluation of the unit process pollutant removal efficiency of various treatment methods. Only by determining the most efficient and economical treatment method will the public be assured of maximum return on its investment.

One physical-chemical treatment method which might be considered is coagulation. Coagulation is the process by which "like-charged" colloidal particles in solution are agglomerated by one or a combination of phenomena into a particle of such weight and size that it will settle by itself. Colloids found in wastewaters are typically negatively charged. The electric properties of these particles tend to keep them in solution in a colloidal state. Two opposing forces affect their relative behavior. The Van der Waals force tends to draw them together while the electrostatic repulsive force tends to keep them apart.

Van der Waals attractive force varies inversely as the square of the distance between the two particles, while the "like-charge" repulsive force decreases exponentially with distance. Only if the kinetic energy of the relative particles is strong enough to overcome the repulsive force to where Van der Waals attractive force predominates, will the colloidal particles coagulate.

Coagulation of a waste may result from two basic phenomena or mechanisms: perikinetic coagulation in which the zeta potential or surface charge of the colloids is reduced by ions of opposite charge to levels below those of Van der Waals attractive force and thus coagulate; or orthokinetic coagulation in which the colloidal particles become trapped on, enmeshed in, or adsorbed by precipitate or "sweep floc" formed by metal hydroxides. Flocculation by organic polyelectrolytes may occur by particle adsorption creating a large blanket of polymer floc which settles, removing trapped particles as it subsides.

O'Melia (5) has described the relationship between the initial colloid concentration and coagulant dosage. For wastes with low initial colloid concentration, a low probability of particle contact exists whereas for high colloid concentrations the reverse is true. Therefore, for coagulation to occur at lower colloid concentration, the presence of additional metal hydroxide precipitate is required, as removal will occur primarily by orthokinetic coagulation; i.e., particles are caught by the large settling mass of precipitates. At higher colloid concentrations, a smaller dosage of coagulant is required, as colloids may be removed primarily by the perikinetic coagulation process. Consequently, the optimum dosage of coagulant will vary depending upon the initial colloid concentration of each sample and with time. The concentration of colloids in stormwater was found to have a high initial concentration indicating that perikinetic coagulation was the predominate phenomena that would occur in chemical treatment of urban stormwaters.

The alkalinity of the waste to be treated plays an important role in the efficiency of the process and the required coagulant dosage, as neutralization of the negatively charged colloids occurs by increasing the amount of positively charged cations, metal complexes, etc. that are prevalent at lower pH's. Alkalinity indirectly provides buffering capacity, making a waste more resistant to pH changes from the addition of metal coagulants such as Al^{+3}. The addition of Alum forms compounds such as

$$Al^{+3} + 4H_2O \rightarrow Al(OH)_4^- + 4H^+$$

which tend to produce excess hydrogen ions tending to lower the pH. The greater the alkalinity, the greater the buffering effect and the greater the addition of alum required to lower the pH to the isoelectric point of the colloid in question.

The range of alkalinities in mg/l as $CaCO_3$ found in urban runoff in Durham varied from 40 to 120, with an average of approximately 80 mg/l, indicative of relatively low alkalinities.

The combination of high colloid concentration and low alkalinity is, according to O'Melia, the easiest system to treat as only optimum coagulant dosage needs to be determined. Destabilization of the colloids is best achieved by positively charged hydrometal complexes produced in acidic ranges.

Jar Test Procedure

The complex chemical reactions involved in coagulation necessitated extensive laboratory experimentation to evaluate optimum conditions for effective pollutant removal. The parameters studied included optimum dosage and pH. Coagulants were evaluated in terms of removal of COD, suspended solids, and turbidity.

Composite urban runoff samples were procured at the main gaging site in 5-gallon, polyethylene containers and were stored at 3°C prior to usage.

A 6-paddle Phipps and Bird jar test apparatus was utilized to determine optimum pH and coagulant dosage. The jar test procedure followed was:

1. Determination of initial coagulant dosage. A one-liter sample was placed on a magnetic stirrer and adjusted to a pH of 6 by the addition of a strong acid or base. Coagulant was added in small doses and flash mixed for one minute followed by three minutes of slow mix. This procedure was continued with successively greater concentrations of coagulant until a visible floc was formed.
2. One liter of sample was placed in each of six 1500 ml beakers and the pH in each beaker was so adjusted as to give a pH range of from 4 to 9 by the addition of a strong acid or base.
3. The coagulant dosage as determined in step (1) was added to each beaker.
4. Each sample was rapid mixed at 80 RPM for 3 minutes, flocculated at 20 RPM for 12 minutes, and allowed to settle under quiescent conditions for 15 minutes.
5. Samples of supernatant from each of the six beakers were analyzed for COD, suspended solids, and turbidity. Sludge characteristics were observed visually.
6. Optimum pH was selected on the basis of supernatant pollutant removal.
7. Steps 2, 4, and 5 were repeated utilizing the optimum pH as determined in step 6 with a varying coagulant concentration in each beaker.
8. Optimum coagulant dosage for optimum pH was chosen on basis of pollutant removal as in step 6.

Coagulants Evaluated

The coagulants evaluated included:

1. Inorganic
    - Alum
    - Ferric chloride
    - Ferrous chloride
    - Lime
2. Organic
    - Anionic
      DOW - A-22 and A-23
    - Non-ionic
      DOW N-11 and N-17
    - Cationic
      DOW C-31, C-32, C-4[illegible] and ET-721
      Calgon WT-2660, ST [illegible]70 and WT-3000

3. Combinations of the preceding

4. Montmorillonite clay and Calgon Aid 18 as coagulant aids

Coagulant Evaluation

A one-liter sample of raw waste was allowed to settle quiescently for 15 minutes during each jar test, without pH adjustment or coagulant addition, to assess the pollutant removal efficiency of sedimentation alone. Supernatant samples were analyzed to determine the percent reduction of COD, suspended solids, and turbidity as compared to a raw mixed sample.

Graphs describing percent removal of suspended solids, COD, and turbidity as a function of pH were developed for each test to determine the pH producing optimum removal efficiency for a fixed coagulant dosage. Representative graphs showing the effect of pH on removal efficiencies for alum, Dow's C-32 and Dow's A-21 are presented in Figures 47, 48, and 49. The optimum pH as recorded indicates the initial pH prior to coagulant addition. The final supernatant pH after coagulation, flocculation, and settling was not necessarily the same. In the case of alum, supernatant pH after treatment was approximately 4.5 - 6.4 whereas initial pH was 6 - 8. In the case of lime, initial pH was 6 - 8, whereas final supernatant pH was 9 to 11, depending on the amount of lime added. The final supernatant pH of the organic polyelectrolytes did not vary significantly from the initial pH. The removal efficiencies of the anionic and non-ionic polyelectrolytes appeared to be less dependent on pH than metal salts or cationic polyelectrolytes.

After selection of optimum pH, varying doses of coagulant addition were evaluated to determine the optimum dose corresponding to the optimum pH. One liter of raw waste samples were again allowed to settle without pH adjustment or coagulant addition to evaluate the pollutant removal efficiency of plain settling. Supernatant from the six jars of varying dosage were analyzed to determine the removal of COD, suspended solids, and turbidity. A graph showing the percent removal of each pollutant versus dosage at optimum pH was constructed. Figures 47, 48, and 49 give representative removal efficiencies of alum, Dow's C-32, and Dow's A-21 as a function of dosage at the optimum pH.

Complete information on all runs for each coagulant evaluated is presented in Table 15. Included in this table is the optimum pH, optimum coagulant dosage, and the initial sample concentration of COD, suspended solids, and turbidity. The removal efficiency of each pollutant by plain sedimentation for each jar test is given. The total percent removed by chemical coagulation and settling is presented. The residual removal efficiency of each coagulant is also presented and is defined as that percent of the residual pollutant concentration not removed by plain sedimentation that was removed only because of coagulant usage. The coagulant residual removal efficiency indicates the specific gain to be realized in pollutant removal over plain settling and compares the relative benefits of individual coagulants.

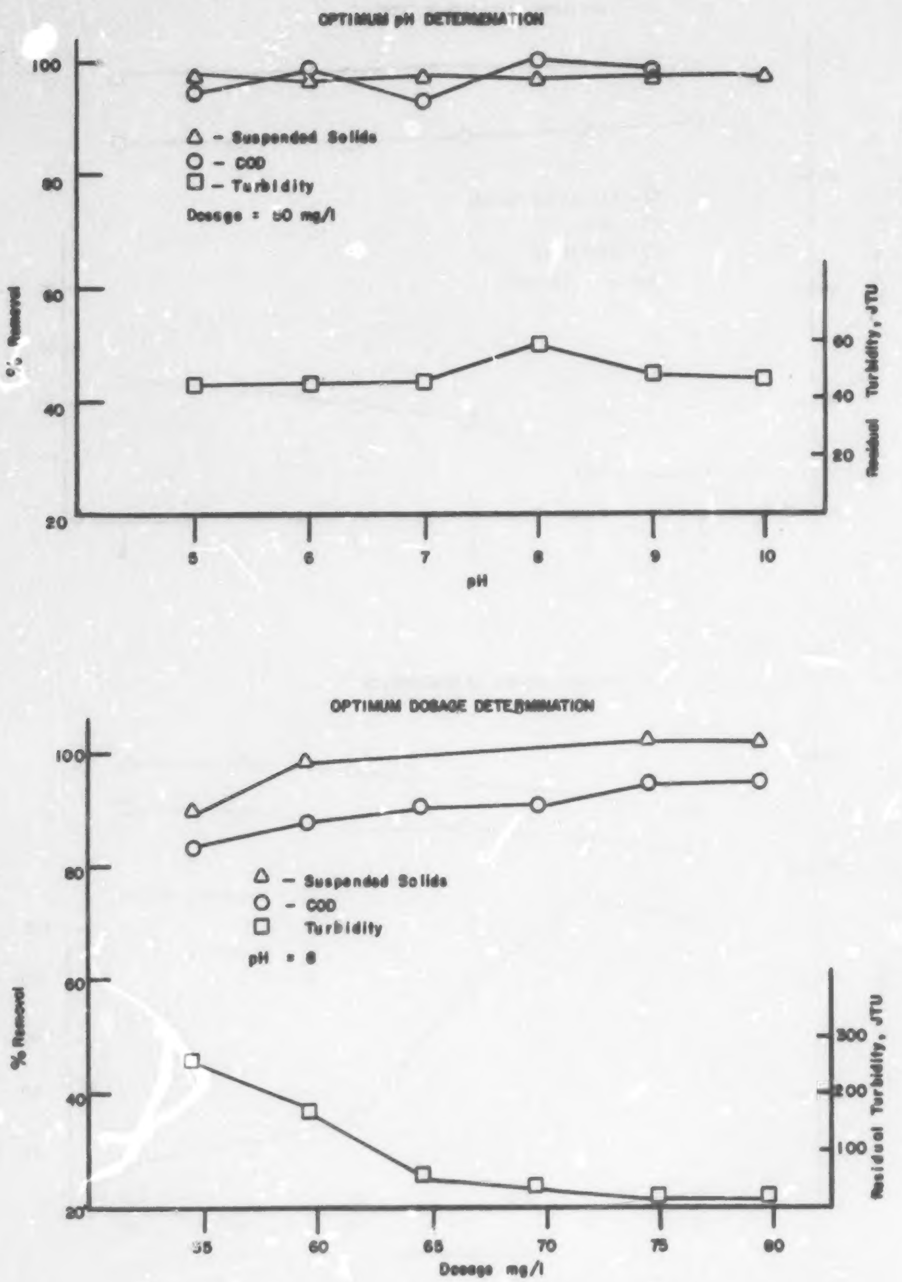
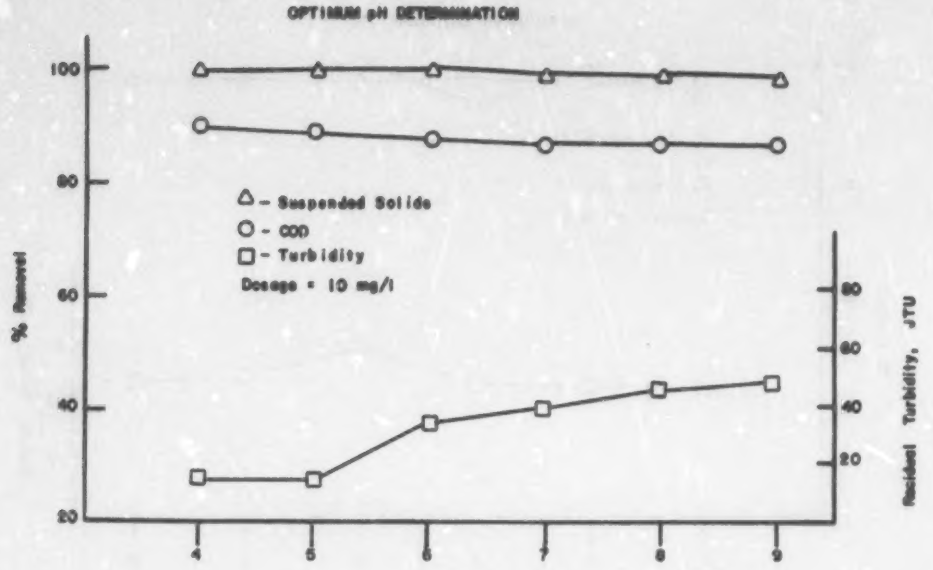


Figure 47. Determination of optimum pH and dosage for alum.



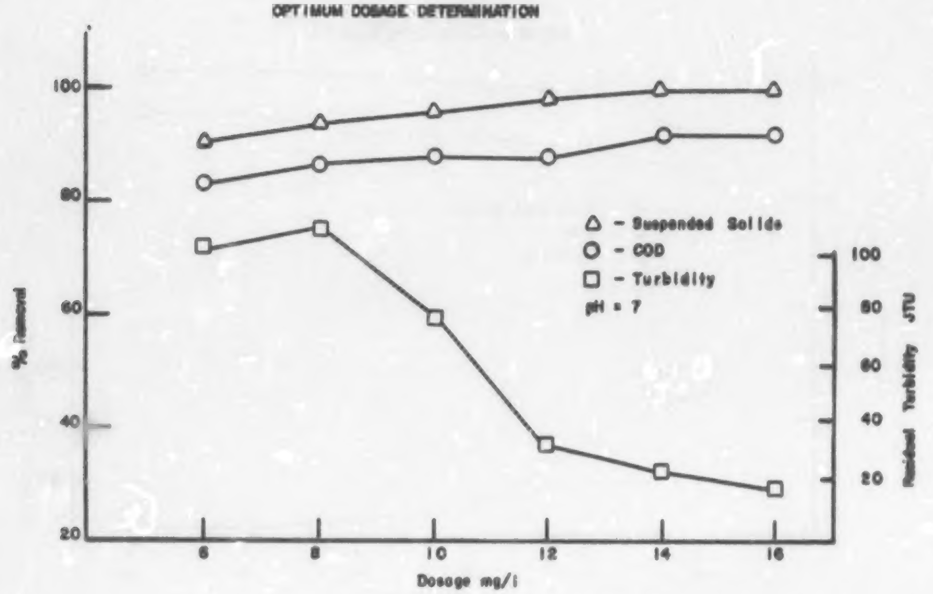


Figure 48. Optimum pH and dosage determination for Dow's C-32.

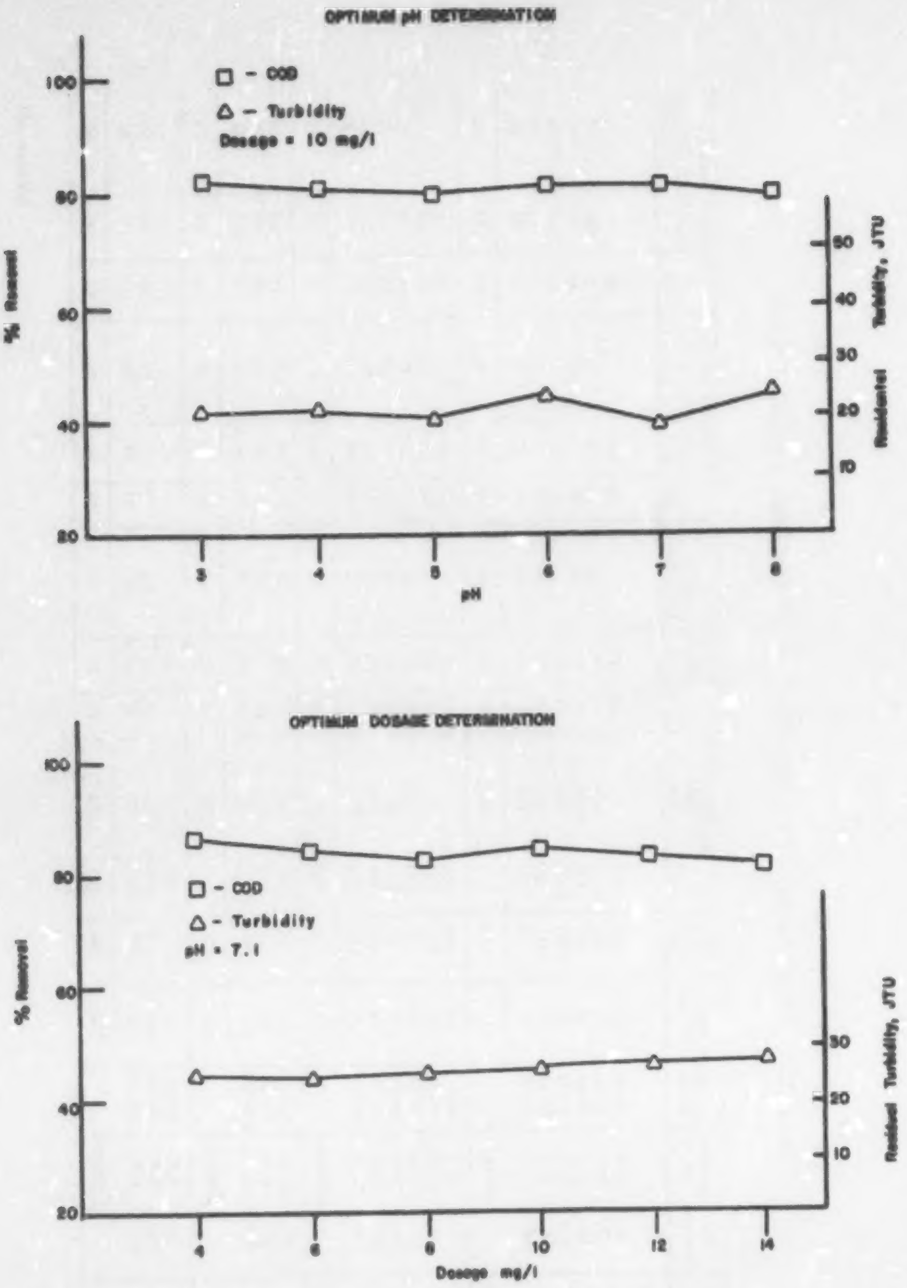


Figure 49. Determination of optimum pH and dosage for Dow's A-22.

Table 15. INDIVIDUAL JAR TEST RESULTS AT OPTIMUM pH AND DOSAGE

Coagulant	Run Number	Optimum pH	Dosage mg/l		Raw Sample Concentration			% Removal by Settling Only			% Removal by Coagulation			Residual Removal Efficiency (%)		
			Range	Optimum	COD mg/l	S.S. mg/l	Turbidity JTU	COD	S.S.	Turbidity	COD	S.S.	Turbidity	COD	S.S.	Turbidity
Inorganics																
Alum	8	6.0	20-70	60	155	420		47	89		80	99		62	91	
	38	8.0	55-80	75	187	2120	753	41	80	61	93	100	98	88	100	95
	39	7.0	20-45	35	119	616	325	65	37	38	88	89	83	66	82	72
	43	8.0	45-70	70	285	1534	753	79	65	22	97	100	99	85	100	99
	48	8.0	20-45	45	227	310	225	46	87	56	64	98	97	33	85	93
	64	7.3	40-70	40	55	324	342	21	30	22	75	87	97	68	81	96
		AVERAGE		54	171	887	480	50	65	40	82	97	94	67	90	91
Ferric Chloride	7	9.0	20-70	20	309	250		47	82		67	83		38	5	
	9	11.0	5-30	25	113	138		42	85		60	94		31	60	
	35	11.0	6-16	16	102	370	159	57	80	46	76	90	81	44	50	65
	36	11.0	18-28	26	99	552	495	55	80	56	82	63	67	60	0	25
	37	12.0	16-26	22	232	508	700	86	85	24	97	87	63	43	13	51
	45	11.0	10-35	35	219	221	216	75	82	61	86	99	94	44	94	85
		AVERAGE		24	179	340	392	60	82	47	77	86	76	43	37	56
Ferrous Chloride	10	11.0	10-60	30	121	294	100	52	88	79	75	100	97	48	100	86
	65	6.8	30-80	80	251	654	303	61	71	17	84	97	83	59	90	79
	66	6.9	200-300	300	390	1018	680	91	88	39	90	96	78	0	67	64
		AVERAGE		137	254	655	361	68	82	45	83	98	86	36	86	76
Lime	5	4.0	20-45	45		102			83			99			94	
	64	6.9	80-180	160	290	700	286	64	77	15	87	98	96	64	91	95
	67	6.9	80-180	160	322	1612	680	88	87	39	97	98	92	75	85	87
		AVERAGE		122	306	805	483	76	82	27	92	98	94	69	90	91

(Continued)

Table 15 (continued). INDIVIDUAL JAR TEST RESULTS AT OPTIMUM pH AND DOSAGE

Coagulant	Run Number	Optimum pH	Dosage mg/1		Raw Sample Concentration			% Removal by Settling Only			% Removal by Coagulation			Residual Removal Efficiency (%)		
			Range	Optimum	COD mg/1	S.S. mg/1	Turbidity JTU	COD	S.S.	Turbidity	COD	S.S.	Turbidity	COD	S.S.	Turbidity
Organics																
Dow C31	11	7.0	6-16	14	104	122	104	45	84	75	47	81	88	4	0	52
	13	6.0	14-24	24	112	386	269	51	74	1	83	98	93	65	92	93
	25	6.8	10-20	10	116	470	302	69	79	41	93	99	95	77	95	91
	26	6.6	4-14	12	510	1026	395	84	90	72	92	98	95	50	80	82
	27	6.8	6-16	14	173	826	512	83	77	63	93	99	95	59	97	86
	54	6.9		20	129	156	243	67	52	51	73	52	65	18	0	28
		AVERAGE		16	191	498	304	66	76	50	80	88	88	45	61	72
Dow C32	12	7.2	4-14	8	119	152	71	38	92	91	56	91	80	29	0	0
	14	6.0	14-24	20	108	160	398	49	51	32	89	97	97	78	94	95
	15	7.4	20-120	20	349	570	260	68	91	55	85	97	95	53	67	89
	29	6.8	10-20	16	112	516	264	42	79	38	70	94	85	48	71	76
	31	7.0	6-16	16	497	1258	412	76	87	63	90	99	96	58	92	89
	57	6.8		20	244	464	495	36	68	60	56	92	93	31	75	82
		AVERAGE		17	238	520	317	51	78	56	74	95	91	49	66	72
Dow C41	20	4.0	20-45	20	125	1456	343	91	95	52	99	96	89	89	20	77
Dow A22	16	7.1	4-14	10	374		361	83		78	85		93	18		68
Dow A23	17	4.0	1-6	5	146		274	76		26	86		43	38		23
Dow N17	18	6.8	6-16	6	129		435	75		48	77		66	8		35
Dow N11	19	6.8	10-20	10	145	356	414	80	95	47	82	84	64	10	0	32
Calgon 266C	24	6.9	10-20	10	997	1130	413	90	97	81	92	100	98	20	43	89
	40	7.2	10-20	10	111	88	113	77	33	15	88	24	73	48	0	68
	41	7.3	4-14	8	25	26	85	1	61	22	2	94	81	1	85	76
	55	6.8		20	263	264	243	25	48	27	47	90	91	29	81	88
		AVERAGE		12	349	377	213	48	60	36	57	77	86	24	52	80

(Continued)

Table 15 (continued). INDIVIDUAL JAR TEST RESULTS AT OPTIMUM pH AND DOSAGE

Coagulant	Run Number	Optimum pH	Dosage mg/1		Raw Sample Concentration			% Removal by Settling Only			% Removal by Coagulation			Residual Removal Efficiency (%)		
			Range	Optimum	COD mg/1	S.S. mg/1	Turbidity JTU	COD	S.S.	Turbidity	COD	S.S.	Trubidity	COD	S.S.	Turbidity
Calgon 2870	21	6.7	8-18	18	112	558	417	87	86	34	96	97	94	69	78	91
	23	4.0	10-20	10	543	438	413	80	96	84	84	98	94	20	50	62
	32	6.9	8-18	18	507	1150	413	74	84	65	87	100	88	50	100	66
	56	6.8		20	252	276	263	12	36	54	50	98	94	43	97	87
		AVERAGE		16	353	605	376	63	75	59	79	98	92	45	81	76
Calgon 3000	22	6.8	10-20	10	496		447	82		85	81		85	0		0

Initially, all coagulants were evaluated once to determine those coagulants showing promise. After the initial evaluation, additional jar tests were performed on the coagulants believed to be most efficient. The organic coagulants were found to be relatively independent of pH in most cases and had COD values themselves. Consequently, it was impossible to determine what portion of the residual supernatant COD was directly attributable to the organic coagulant.

The coagulants selected for additional jar testing were alum, lime, ferric chloride, Dow's C-31 and C-32, and Calgon's WT-2660 and WT-2870. The results of these additional evaluations of optimum pH and dosage are also included in Table 15.

Coagulant Aid Evaluation

After evaluating the removal efficiencies of the individual coagulants and selecting those with promising removal efficiencies, a study of the use of various coagulant aids was initiated to determine if the addition of coagulant aid with alum, ferric chloride, Dow's C-31, Dow's C-32, Calgon's 2660 and 2870 would bring about increased removal efficiencies by the primary coagulant.

Complete jar tests, including determination of optimum pH and coagulant aid doses, were made with prior addition of the optimum dose of the primary coagulant as previously determined. The coagulant aids evaluated with alum and ferric chloride were Calgon Aid 18, Dow's C-32, and Calgon's 2870. The coagulant aids evaluated for use with the cationic polyelectrolytes included Calgon Aid 18 and montmorillonite clay. One liter of raw sample was again allowed to settle without any pH adjustment or coagulant addition for 15 minutes to evaluate the removal efficiency of plain settling. Table 16 gives optimum coagulant aid dosage, optimum pH and associated COD, solids, turbidity removals for coagulation and the residual efficiency of each coagulant aid combination for each jar test.

Coagulant Selection

The average COD removal efficiency for 15 minutes of ideal quiescent settling for 53 observations was 61 percent with a range from 1 to 91 percent. Average suspended solids removed by quiescent settling was 77 percent with a range from 33 to 95 percent, while the average turbidity removal was 53 percent from settling alone with a range from 1 to 91 percent.

The wide range of removal efficiencies for plain sedimentation was due to variations in quality of the raw sample as shown by the characterization of urban runoff with respect to these specific contaminants. Not all jar tests could be run immediately after sample procurement as the tests are very time consuming. An average run of optimum pH and dosage with six jars each, with duplicate COD's, suspended solids, and turbidity easily took one man a week including preparation and analysis. Consequently, sample characteristic changes could have occurred as a

Table 16. INDIVIDUAL JAR TEST RESULTS FOR COAGULANT AIDS

Coagulant Plus Coagulant Aid	Run Number	Coagulant Aid Dosage		Optimum pH	Raw Sample Concentration			% Removal by Settling Only			% Removal by Coagulation			Residual Removal Efficiency (%)		
		Range	Optimum		COD mg/l	S.S. mg/l	Turbidity JTU	COD	S.S.	Turbidity	COD	S.S.	Turbidity	COD	S.S.	Turbidity
45 mg/l Alum plus:																
Calgon Aid 18	51	4-14	14	8.0	136	508	225	66	85	65	91	99	99	73	93	97
Dow C-32	50	2-10	4	8.0	134	356	198	56	73	87	88	95	97	72	81	77
Calgon 2870	49	2-12	8	8.0	219	328	248	45	68	59	66	99	98	38	97	95
Mont. Clay	65	5-25	15	7.3	55	324	342	21	30	22	75	87	97	68	81	96
35 mg/l Ferric Chloride plus:																
Calgon Aid 18	52	4-14	8	11.0	190	246	181	50	80	76	66	98	93	32	90	71
Dow C-32	47	2-10	8	11.0	166	516	207	60	79	62	81	96	98	52	81	95
Calgon 2870	46	1-10	1	11.0	160	366	225	76	70	68	85	92	89	37	73	66
20 mg/l C31 plus:																
Montmt. Clay	28	10-18	14	6.8	79	338	342	56	80	68	80	95	96	54	75	87
Calgon Aid 18	58	4-20	20	6.9	129	156	243	67	52	51	93	52	85	79	0	69
20 mg/l C32 plus:																
Calgon Aid 18	30	6-16	16	6.8	74	438	445	55	93	76	79	99	97	53	86	87
Mont. Clay	61	4-20	20	6.8	244	464	495	36	68	60	62	98	98	41	94	95
20 mg/l Calgon 2660 plus:																
Mont. Clay	59	4-20	12	6.8	263	264	243	25	48	27	50	96	95	33	92	93
Mont. Clay	63	8-16	16	7.3	55	324	342	21	30	22	75	96	96	68	94	95
				AVERAGE	159	294	292	23	39	24	62	96	95	50	93	94
20 mg/l Calgon 2870 plus:																
Mont. Clay	60	4-20	16	6.8	252	276	263	12	36	54	48	99	95	41	98	89
Mont. Clay	62	12-20	12	7.3	55	324	342	21	30	22	61	92	89	51	88	86
				AVERAGE	153	300	302	16	33	38	54	95	92	46	98	87

result of storage, even though samples were stored at 3°C and completely mixed prior to usage.

The relative advantages of a coagulant should be evaluated on the characteristic residual removal efficiency as this parameter reflects the relative ability of a specific coagulant to remove that fraction of the pollutant load not susceptible to removal by plain sedimentation. The coagulants evaluated are ranked according to the average residual removal efficiency of COD, suspended solids, and turbidity in Table 17. The removal efficiency of plain sedimentation used to construct the table are those for the particular run in question and not the average of all the sedimentation tests.

Table 17. COAGULANT RANKING ON AVERAGE RESIDUAL REMOVAL EFFICIENCY OF COD, SUSPENDED SOLIDS, AND TURBIDITY

Rank	Coagulant	Average residual removal efficiency (%)
1	Alum + Calgon Aid 18	88
2	Alum	83
	Lime	83
4	Alum + Montmorillonite Clay	82
5	Calgon 2660 + Montmorillonite Clay	79
6	Calgon 2870 + Montmorillonite Clay	77
	Alum + Dow C-32	77
	Alum + Calgon 2870	77
	Dow C-32 + Montmorillonite Clay	77
10	Ferric Chloride + Dow C-32	76
	Dow C-32 + Calgon Aid 18	76
12	Dow C-31 + Montmorillonite Clay	72
13	Calgon 2870	67
14	Ferrous Chloride	66
15	Ferric Chloride + Calgon Aid 18	64
16	Dow C-32	62
	Dow C-41	62
18	Dow C-31	59
	Ferric Chloride + Calgon Aid 18	59
20	Calgon 2660	52
21	Dow C-31 + Calgon Aid 18	49
22	Ferric Chloride	45
23	Dow A-22	40
24	Dow A-23	32
25	Dow N-17	22
26	Dow N-11	14
27	Calgon 3000	0

Alum, with and without Calgon Aid 18 and montmorillonite clay, was judged the most effective coagulant. At optimum conditions, total removals of COD, suspended solids, and turbidity of 84, 97, and 94 percent, respectively, were realized with an average residual removal efficiency as previously defined of 82-88 percent over plain sedimentation. The supernatant had a very clear appearance, and the floc settled easily. The optimum and final pH was approximately neutral, thus requiring no pH adjustments. Alum also has the advantage of being readily available, relatively inexpensive, good storage characteristics, non-toxic, and easily applied.

Iron salts, with and without aids, was less effective than alum. The optimum pH of 9 to 11 would require the use of a strong base to achieve the optimum pH and the use of a strong acid to reduce the pH prior to discharge to the receiving watercourse. Iron salts left a residual turbidity and characteristic iron color in the supernatant.

Lime produced an average total removal of COD, suspended solids, and turbidity of 92, 98, and 94 percent and had an excellent residual removal efficiency of 83 percent. Lime, like alum, provided a clear supernatant with good floc characteristics. The high lime dosage at the optimum pH, however, left the supernatant with a pH of approximately 10 which would require the use of a strong acid prior to release to a receiving watercourse. The optimum lime dose in mg/l was higher than that for alum.

Cationic polyelectrolytes in general were associated with good removal efficiencies with and without coagulant aids. Calgon's 2660, 2870, and Dow's C-32 with montmorillonite clay were judged most effective of all cationic coagulants evaluated. The Milk River Project (6) reported that concentrations of Dow's C-31 and C-32 in the range of 3 - 5 mg/l were detrimental and/or fatal to fish. Consequently, any overdose of C-31 or C-32 resulting in supernatant concentrations of cationic polyelectrolytes could not be released to a receiving watercourse without further evaluation. Calgon's 2660 and 2870 and other cationic polyelectrolytes have not been evaluated in terms of toxicity. It is, therefore, important to carefully assess and evaluate environmental impacts of these cationic polyelectrolytes.

Coagulant aids, Calgon Aid 18 and montmorillonite clay, were judged useful in increasing the removal characteristics of the individual coagulants. Both increase the particle or nucleus concentration in the waste and perhaps absorb some of the organics. The specific values attached to the usage of varying coagulant aids should be assessed for individual applications.

Based on removal efficiency and the above-mentioned important considerations, alum, with or without clay-type coagulant aids, is judged the most effective coagulant for treatment of urban land runoff in Durham, North Carolina. Within the choices of treatment alternatives, plain sedimentation is a reasonable, relatively inexpensive alternate to chemical treatment of urban land runoff.

Batch Scale Coagulant Evaluation

After final evaluation of the jar tests on each coagulant, batch scale coagulation, flocculation, and sedimentation tests were run. The purpose was to observe scale up effects, if any, and to determine settling rates and sludge characteristics.

A schematic of the 15-gallon batch process is shown in Figure 50. Approximately 17 gallons of raw waste was placed in the rapid-mix tank. The pH was adjusted and the correct amount of coagulant added. The mixture was then agitated at approximately 6000 RPM for three minutes and then transferred by a centrifugal pump to the flocculation and settling column. The plexiglass column was 10 feet tall with an inner diameter of 6-1/4 inches. A one-inch aluminum shaft with two-inch-square paddles at intervals of one foot were placed in the middle of the column for flocculation. The shaft was rotated at 20 RPM for 12 minutes by a chain drive located at the top of the shaft. After flocculation the waste was allowed to settle. Sampling ports, located at one-foot intervals, were used during the settling process to develop the settling rate-time relationship. The results obtained were expressed in terms of percent removal of suspended solids at each sampling port and time interval. These removals were plotted against their respective depths and times. Smooth curves were drawn connecting points of equal removal. The curves

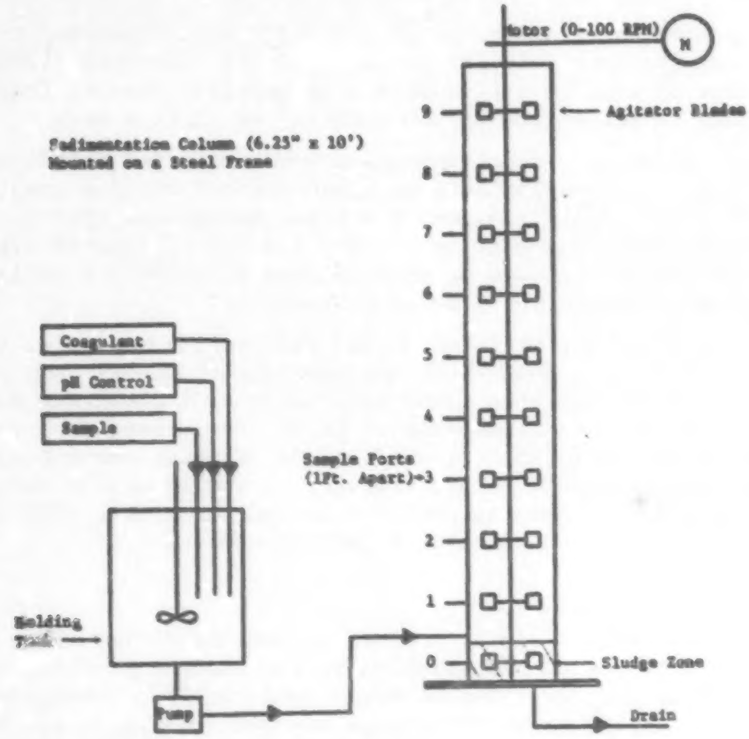

Motor (0-100 RPM)
M
Agitator Blades
Sedimentation Column (6.25" x 10')
Mounted on a Steel Frame
9
8
7
6
5
4
Sample Ports
(1Ft. Apart)-3
2
1
0
Sludge Zone
Coagulant
pH Control
Sample
Holding
Tank
Pump
Drain

Figure 50. Schematic of batch coagulation-sedimentation column.

represent the limiting or maximum settling path for the indicated percent. In other words, the specified percent solids will have a settling path equal to that shown and would, therefore, be removed in an ideal settling tank of the same depth and detention time. The areal overflow rate for an ideal settling basin could then be found by dividing the effective depth by the time required for a given iso-removal line to settle this depth.

Representative iso-removal lines for selected coagulants are presented in Figures 51 and 52. These were constructed for each batch test to assess the areal overflow rate in gallons per day per square foot of surface area associated with varying suspended solids removal rates. These overflow rates are for ideal quiescent settling and would have to be adjusted depending on the relative efficiency of a designed sedimentation basin.

Figure 53 gives the relationship of the percent removal of suspended solids as a function of areal overflow rate for Dow's C-31, Dow's C-32 and Calgon's 2870. The doses utilized were those found to be optimum in prior jar tests. On each of the four runs a 90 percent suspended solids removal was attained at overflow rates of up to approximately 4000 GPD/ft^2 and in some cases up to 6000 GPD/ft^2.

Figure 54 gives the relationship of suspended solids removal as a function of areal overflow rate for ferric chloride. Removal efficiencies as a function of areal overflow rate were sporadic varying from 55 to 96 percent at an overflow rate of 6000 GPD/ft^2 of surface area.

Figure 55 describes the relationship between suspended solids removal and areal overflow rate for alum with and without various coagulant aids. A 92 to 97 percent suspended solids removal was typically attained at overflow rates of up to 6000 GPD/ft^2 of surface area. Run Nos. 1 and 5 did not produce as good removal efficiencies as the other runs. The exact reason for this is unknown.

The areal overflow rate utilized in the jar testing was calculated to be 240 GPD/ft^2 of surface area which was substantially less than the magnitude of areal overflow rates found to produce equivalent suspended solids removals in the column tests. It is, therefore, apparent that the 15-minute settling time utilized in the jar test was extremely conservative. The suspended solids removals of the 15-gallon batch tests are approximately the same as achieved in the jar tests, thus indicating little, if any, scale-up effects on percent removal.

Sludge Characterization

During the final stages of the project it was deemed important to gain some insight into the characteristics of the sludges produced as a result of chemical coagulation of urban land runoff. Consequently, during the last 5 column tests the sludge was withdrawn from the bottom of the sedimentation column. The unit weight, percent solids, and specific resistance of the sludge was determined. The specific resistance was determined by the Buchner funnel apparatus as described by Eckenfelder (3).

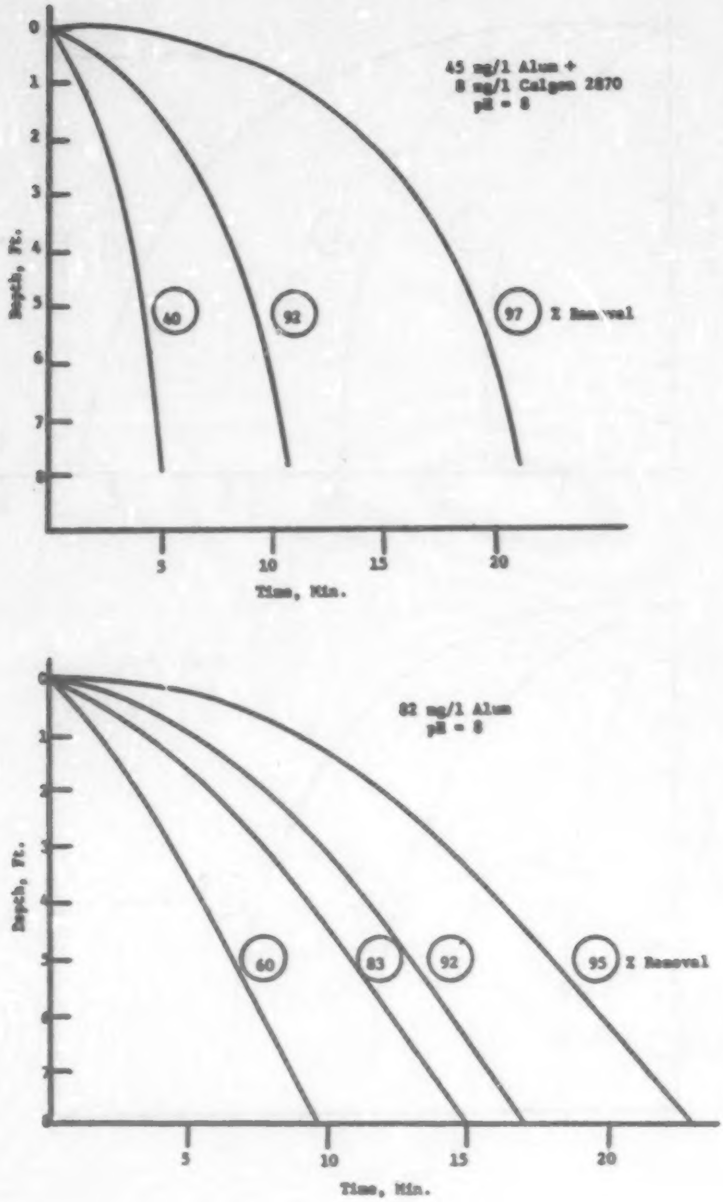


Figure 51. Suspended solids removal as a function of detention time.

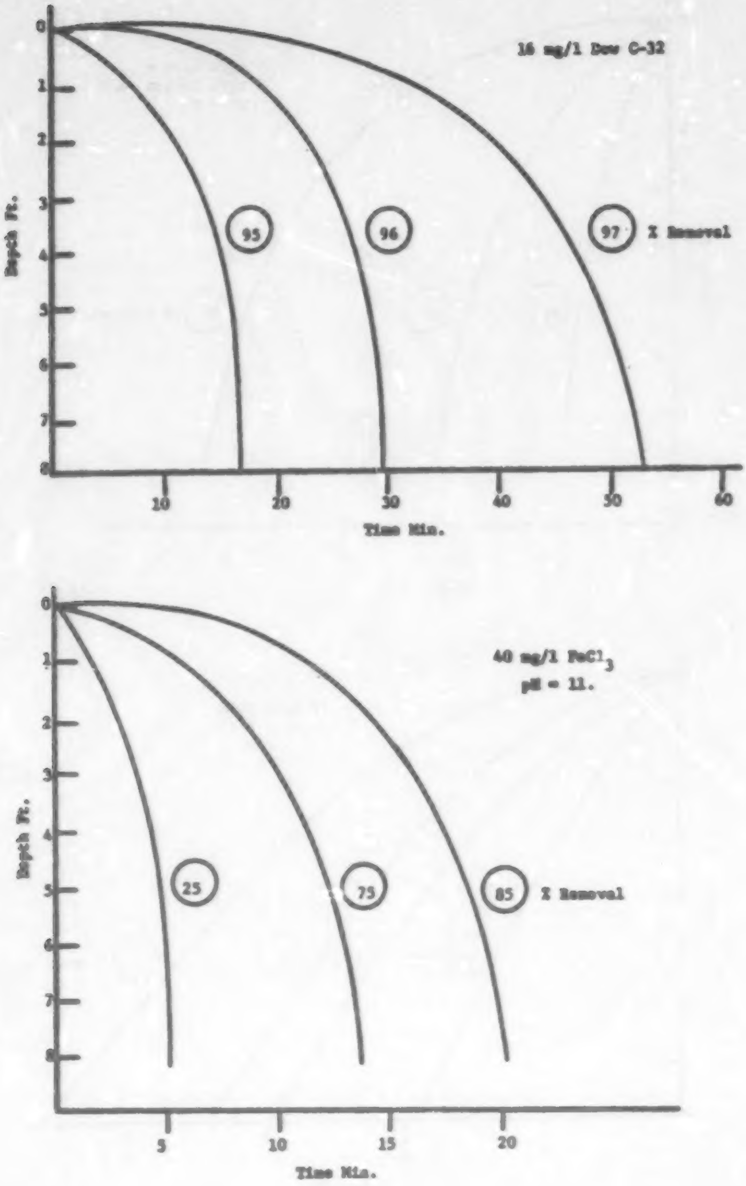


Figure 52. Suspended solids removal as a function of detention time.

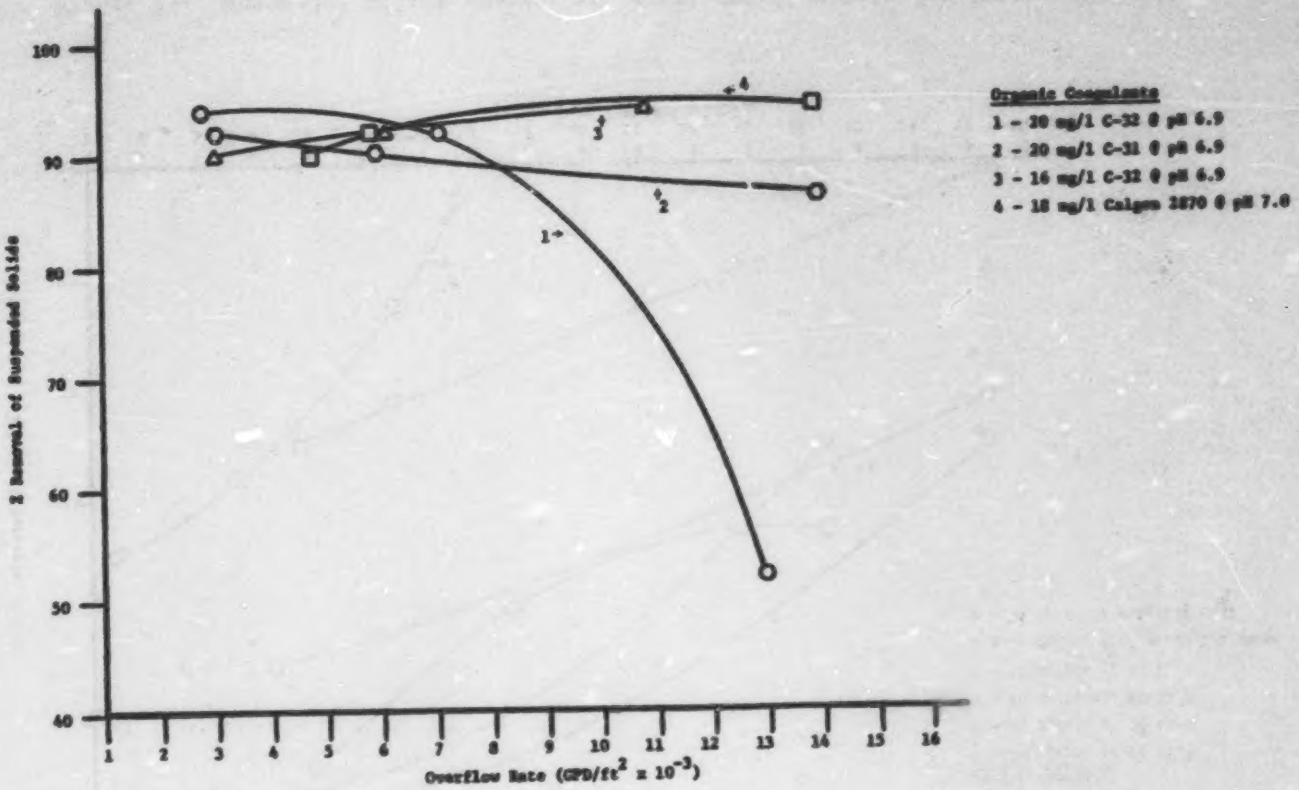


Figure 53. Suspended solids removal vs. areal overflow rate for cationic polyelectrolytes.

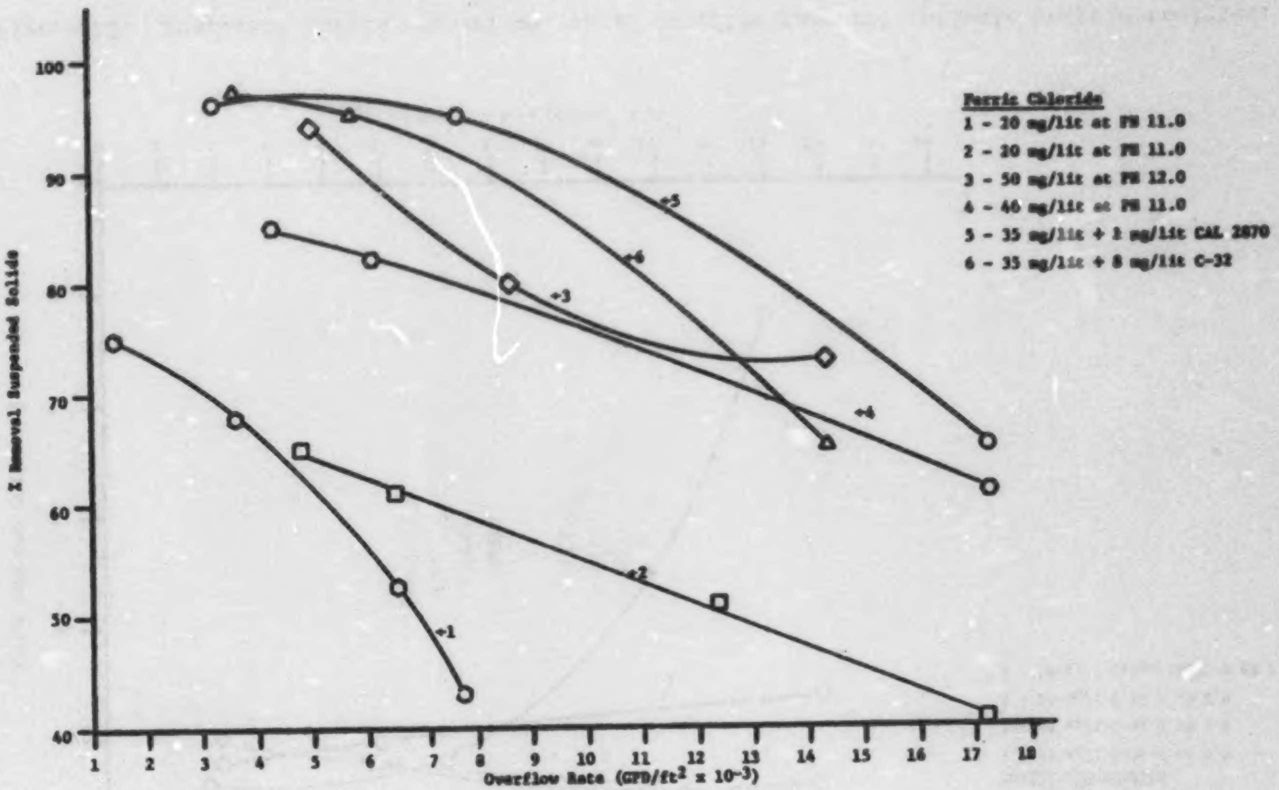


Figure 54. Suspended solids removal vs. areal overflow rate for ferric chloride.

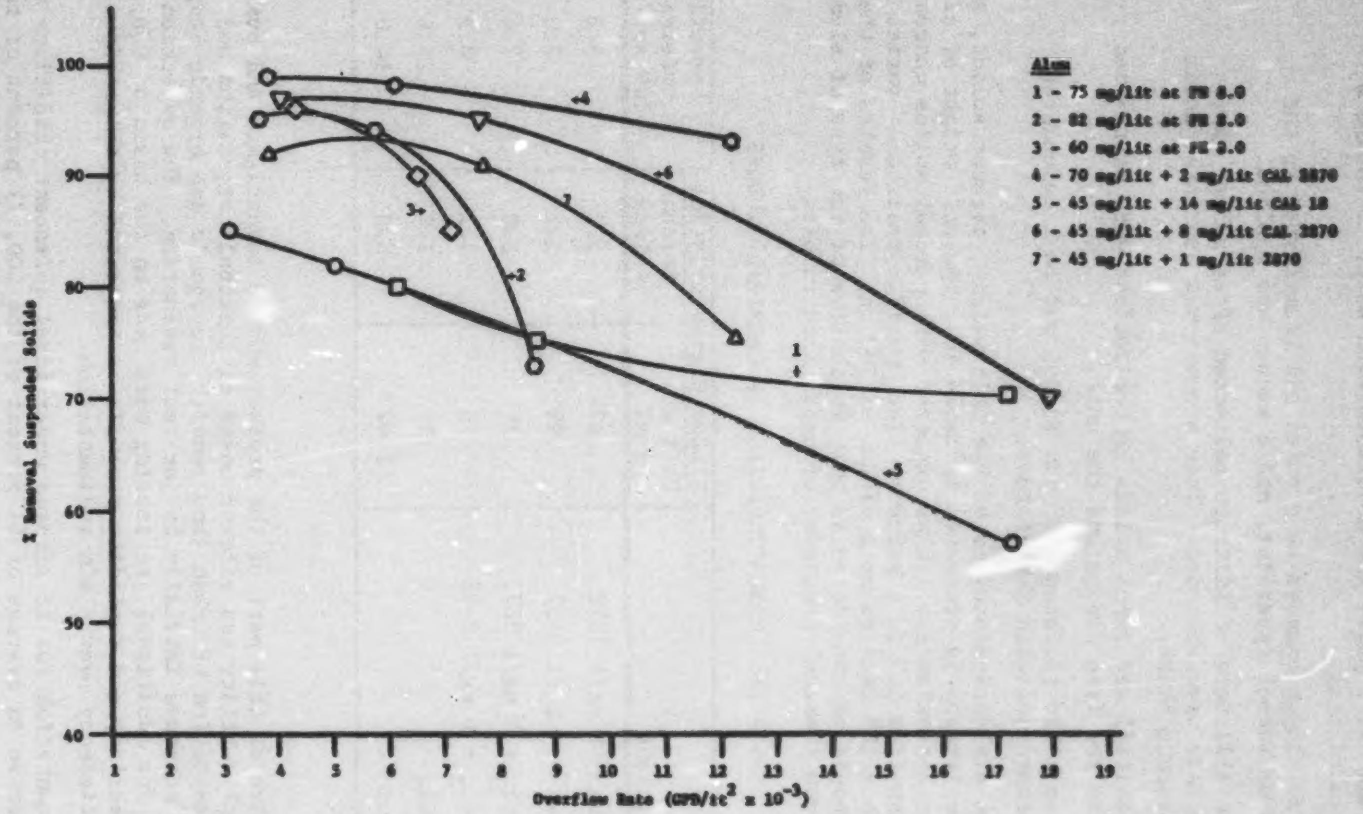


Figure 55. Suspended solids removal vs. areal overflow rate for alum with and without coagulant aids.

The procedure followed was:

1. Whatman No. 2 paper was moistened with water to ensure a completed seal.
2. 200 ml sludge samples were mixed and transferred to the Buchner funnel apparatus, and a vacuum was applied.
3. The milliliters of filtrate collected after select time intervals were recorded. This process was continued until the vacuum broke.
4. The initial and final solids concentrations were determined in the raw feed sludge and the cake.
5. The specific resistance of the sludge was then calculated in accordance with Eckenfelder.

Each of the six determinations of the unit weight, percent solids, and specific resistance is presented in Table 18. The unit weight of all sludges was approximately 1.0 as expected with percent solids concentration varying from 1.3 to 6 percent. The specific resistance varied from 3.0 to 25.6 x 10^8 sec^2/gm at a vacuum of 700 mm. The results of these six runs should be considered as only indicative of the type of sludge obtained from chemical treatment of urban land runoff.

Table 18. CHARACTERISTICS OF CHEMICAL SLUDGES

Coagulant	Sludge Characteristics		Specific resistance 10^8 sec^2/gm
	Unit wt. gm/ml	Percent solids	
45 mg/l Alum + 8 mg/l 2870	.97	1.3	3.0
45 mg/l Alum + 4 mg/l C-32	.98	1.2	7.0
35 mg/l $FeCl_3$ + 1 mg/l 2870	.99	3.0	7.4
35 mg/l $FeCl_3$ + 8 mg/l C-32	.98	3.1	8.9
40 mg/l $FeCl_3$	.96	1.8	25.6
60 mg/l Alum	1.02	6.0	14.0

Summary

The objective of this part of the project was to investigate and evaluate the applicability and effectiveness of chemical coagulation and plain sedimentation of urban land runoff. Inorganic and organic coagulants were screened initially by jar test evaluation. The selection of coagulants for additional jar testing were made on the basis of COD, suspended solids, and turbidity removals as indicated by the residual removal efficiency over plain sedimentation.

Plain sedimentation for 15 minutes under ideal quiescent conditions was found to remove an average of 61 percent of the COD, 77 percent of the suspended solids, and 53 percent of the turbidity. Alum, with or without coagulant aids, was judged to be the most effective coagulant for chemical treatment of urban land runoff based on removal efficiencies and optimum conditions. An average of 57 mg/l of alum was found to affect removals of COD, suspended solids, and turbidity of 84, 97, and 94 percent, respectively.

Batch scale chemical treatment studies indicated little, if any, scale-up difficulties for chemical treatment. Areal overflow rates of up to 6000 gallons per day per square foot of surface area under ideal conditions produced 92 to 97 percent removal of suspended solids.

Plain sedimentation, being much less costly than chemical coagulation, removed a significant portion of organics and solids and should be considered as the first alternative in treatment of urban land runoff. Chemical coagulation with alum produces significant increases in pollutant removal over plain sedimentation and should be considered an effective tool for preventing adverse effects of urban land runoff on water quality management.

SECTION VIII

RELATIVE IMPACT OF URBAN LAND RUNOFF

Introduction

The relative impact of urban land runoff on water quality is dependent on the physical, chemical, and biological characteristics associated with the particular aqueous system receiving the waste. As each receiving watercourse tends to differ, the impact--relative or absolute--is different. Consequently, each municipality must assess the magnitude of urban runoff for its particular situation. In this project the pollution originating as non-point urban runoff was evaluated in two ways in an attempt to provide insight into its relative impact on a receiving watercourse. First, the annual pollutant yield of urban runoff was evaluated in comparison to municipal waste in terms of pounds and concentrations. Second, the influence of urban land runoff on dissolved oxygen concentrations in a hypothetical situation was evaluated with respect to point sources.

Comparison with Domestic Waste

The 1.67 square-mile study area is served by the Durham Third Fork activated sludge sewage treatment plant which receives wastes from a total area of 9.6 square miles. The average daily waste volume during 1972 was 3.3 MGD with average raw waste concentrations of 205 mg/l suspended solids, 285 mg/l 5-day BOD, 7 mg/l total phosphorus as "P," 4.4 mg/l nitrate nitrogen, 0.06 mg/l chromium, 0.12 mg/l copper, 0.9 mg/l zinc, <0.5 mg/l lead, and <0.1 mg/l nickel. The plant's average removal efficiency for BOD_5 and suspended solids was 91 and 85 percent, respectively. As a result of the long-term COD uptake rates described previously, it was determined that approximately 50 percent of the total initial COD of urban runoff could be biologically degraded in twenty days. Because of the difficulties experienced with running BOD tests on urban runoff, the ultimate BOD of urban runoff is assumed to be equal to the percent of the COD susceptible to biodegradation. As no COD tests were run at the Durham sewage treatment plant, it is assumed that the 5-day BOD is 68 percent of the ultimate and that the COD of the raw municipal waste is 150 percent of the ultimate BOD. Therefore, the COD of the raw municipal waste is 2.2 (i.e., $1.5 \div 0.68$) times the 5-day BOD as measured.

Table 19 compares total quantities of raw municipal wastes and urban runoff, including base flow, in pounds per acre per year of drainage basin size. The contribution of urban runoff reflects the adjusted contribution as described previously in Table 14. Urban runoff contains the majority of the heavy metals varying from 57 percent of the total zinc yield to 94 percent of the chromium. It is important to note that if Durham provided 100 percent removal of organics and suspended solids from the raw municipal waste on an annual basis, the total reduction of pollutants discharged to Third Fork Creek would only be 52 percent of the COD, 59 percent of the ultimate BOD, and only 5 percent of the total suspended solids.

Table 19. COMPARISON OF RAW MUNICIPAL WASTE AND URBAN RUNOFF ON AN ANNUAL BASIS IN POUNDS PER ACRE PER YEAR POLLUTANT YIELD

Pollutant	Raw municipal waste		Urban Runoff* + base flow		Total annual yield
	lbs	%**	lbs	%**	
COD	1027	52	938	48	1965
BOD Ultimate	685	59	470	41	1155
Suspended Solids	335	5	6690	95	7025
Kjeldahl Nitrogen as "N"			6.1		
Nitrate "N"	7.2				
Total Phosphorus as "P"	11	73	4.7	27	15.7
Chromium	.10	6	1.6	94	1.7
Copper	.20	11	1.6	89	1.8
Lead	<.8	21	2.9	79	3.7
Nickel	<.16	12	1.2	88	1.3
Zinc	1.5	43	2.0	57	3.5

* See Table 13.

** % of total annual yield.

Table 20 gives the total annual yield of pollutants from municipal and urban runoff sources in pounds per acre during 1972 based on actual removal rates for the Durham Third Fork Sewage Treatment Plant. On a yearly basis the average ultimate BOD reduction is 46 percent, COD--48 percent, and suspended solids--4 percent.

Table 20. TOTAL ANNUAL YIELD OF POLLUTANTS FROM MUNICIPAL AND URBAN RUNOFF WASTES IN POUNDS/ACRE DURING 1972

Parameter	Municipal waste			Urban runoff	Total release	Overall removal efficiency
	Raw	Percent removal	Effluent			
COD	1027	91*	92	938	1030	48%
Ultimate BOD	685	91	61	470	531	46%
Suspended Solids	335	85	50	6690	6740	4%

*Assumed

Table 21 evaluates the total yield of pollutants from the Third Fork Creek watershed during those times of urban runoff, which occurred 19 percent of the time or 1680 hours during the year. The urban runoff contribution used to construct this table does not include pollutant yield during the 7080 hours of base flow. During the 1680 hours of wet weather the raw municipal wastes represent only 18 percent of the total yield of COD, 23 percent of the ultimate BOD, and only 1 percent of the total suspended solids load. Consequently, if Durham provided 100 percent treatment of municipal wastes during these periods, it would represent an overall reduction of only 18, 23, and 1 percent of COD, ultimate BOD, and suspended solids to the receiving watercourse.

Table 21. TOTAL YIELD OF POLLUTANTS DURING STORM PERIODS FROM URBAN RUNOFF AND RAW MUNICIPAL WASTES IN LBS/ACRE DURING 1972

Parameter	Raw municipal wastes	Urban runoff	Total	Percent Municipal	Percent Runoff
COD	195	895	1090	18	82
Ultimate BOD	130	447	577	23	77
Suspended Solids	64	6617	6681	1	99

It is important to note that approximately 20 percent of the time downstream water quality is not controlled by municipal wastes but by urban runoff. Even if all raw sewage were completely removed during storm events, the relative influence on downstream quality would be minimal compared to the impact of urban land runoff.

Relative Impact on Downstream Oxygen Content

The dissolved oxygen content of water in the drainage system is an important indicator of the life-sustaining capability of the stream. In investigating the impact of urban stormwater on downstream oxygen content, there are many variables which have significant effects. To apply the results of the present research to this question, it was necessary to hypothesize an artificial downstream reach in order to reduce the number of variables to a manageable and meaningful level.

Study Area Characteristics

The watershed selected for study is shown in Figure 56. It is larger than and includes the watershed from which the source data for this research were taken. The study watershed has a drainage area of 9.6 square miles. The effluent of the Third Fork Creek Waste Treatment Plant of the City of Durham is discharged into the stream at the outlet of the study basin. The study watershed is urbanized to the same degree as the watershed monitored.

The reach of interest was the segment of Third Fork Creek below the municipal waste treatment plant.

Problem Formulation

The question was investigated by applying the Streeter-Phelps oxygen-sag equations to the mixed streams issuing from the study watershed and from the municipal waste treatment plant. The coordinates of the sag point were determined as follows:

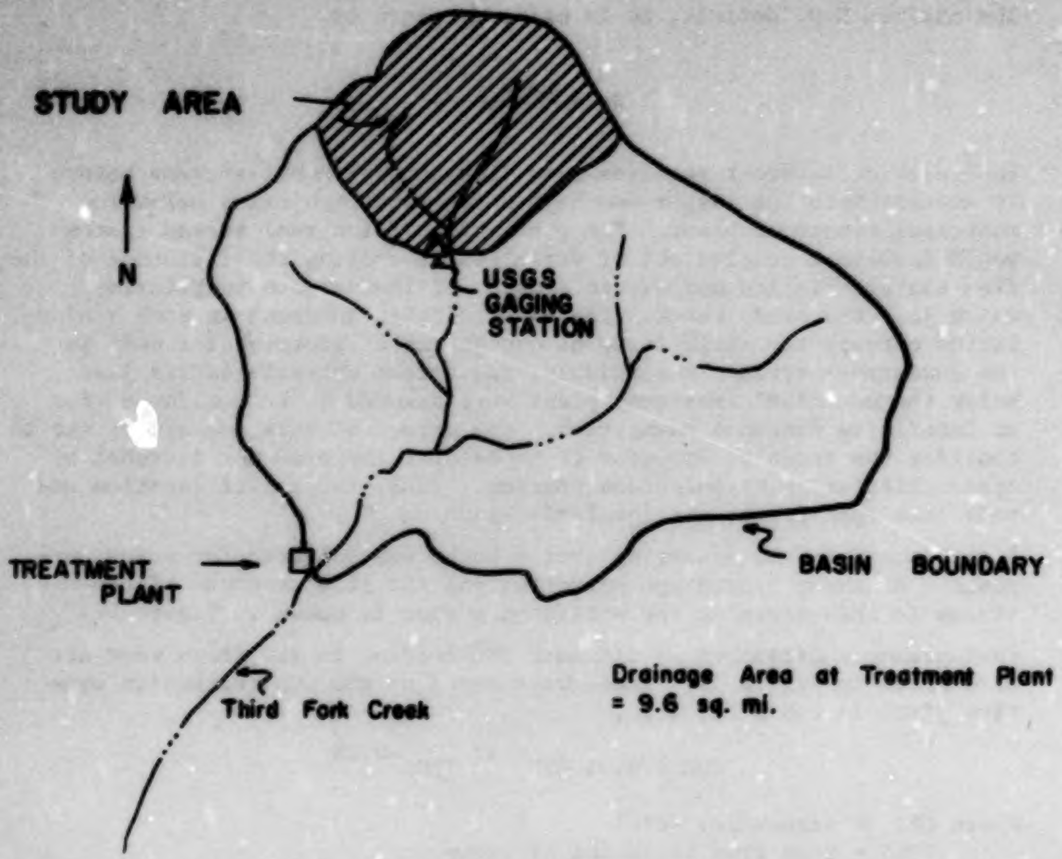

STUDY AREA
N
USGS GAGING STATION
TREATMENT PLANT
BASIN BOUNDARY
Third Fork Creek
Drainage Area at Treatment Plant = 9.6 sq. mi.

Figure 56. Watershed selected for oxygen sag studies.

The time to the sag point is given by:

$$t_c = \frac{1}{k_1(f-1)} \ln \{f[1-(f-1)\frac{Da}{La}]\}$$

where t_c = flow time to the sag point (days)

k_1 = deoxygenation rate constant of the waste, base-e form (per day)

$f = k_2/k_1$

k_2 = reoxygenation rate constant of the stream, base-e form (per day)

Da = initial dissolved oxygen deficit, relative to saturation (mg/l)

La = initial ultimate BOD (mg/l)

The maximum D.O. deficit, Dc in mg/l, is given by

$$Dc = \frac{La\, e^{-k_1 t_c}}{f}$$

The reach of interest receives flow from several minor streams before it empties into the larger New Hope Creek about ten miles below the municipal treatment plant. The simulation of the real stream system would involve a complex set of variables describing the influence of the flow characteristics and oxygen demands of the various tributaries which join the study reach. The uncertainties inherent in such a simulation obscure the basic issue of the impact of stormwater runoff in the downstream areas. Accordingly, the stream characteristics just below the municipal treatment plant were assumed to be continuous for an indefinite distance downstream. The effect of this assumption was to consider the reach of interest to be neither improved nor degraded by other tributaries or pollution sources. Thus, the impact question was made less specific to the local situation.

A one-inch rainfall occurring over 5 hours was selected for study purposes. A linear hydrograph approximating the flow response of the stream to this storm at the watershed outlet is shown in Figure 57.

Instantaneous estimates of ultimate BOD loading in the storm wave are also shown in Figure 57. These were based on the COD regression equation given in Table 11; i.e.,

$$COD = 0.51\ CFS^{1.11}\ TFSS^{-0.28}$$

where CFS = streamflow (cfs)
TFSS = time from beginning of storm (hr)
COD = chemical oxygen demand (lb/min)

This equation estimates COD near the stream bottom. Average COD for the stream appears to be 84 percent of this value. Further, 44 percent of the COD is estimated to be biodegradable. Using these figures, together with the appropriate unit conversion factor, the estimating equation for ultimate BOD is

$$BOD_u = 11.2\ CFS^{1.11}\ TFSS^{-0.28}$$

where BOD_u is expressed in lb/hr.

The value of the reaeration coefficient, k_2, is strongly influenced by the shape of the channel cross-section and the magnitude of flow. For the purpose of estimating the value of the reaeration coefficient, the formulation of O'Connor and Dobbins (4) was used. Restated in the base-e form, their equation under conditions of non-isotropic turbulence is

$$k_2 = 1100\ D_L^{0.5} S^{0.25} H^{-1.25},$$

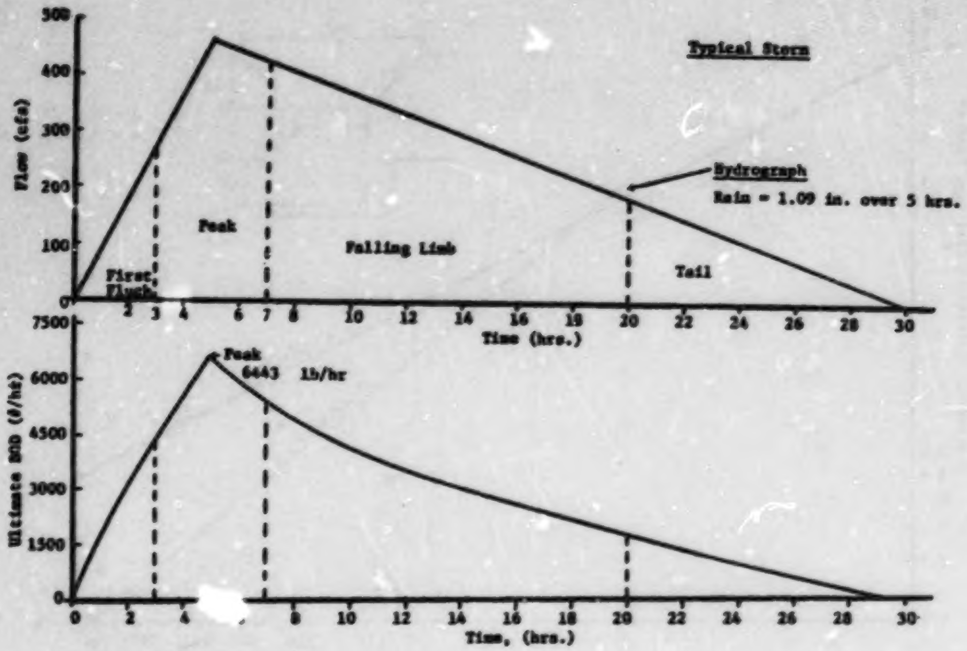


Figure 57. Typical storm for conditions at Third Fork Creek treatment plant.

where k_2 = reaeration coefficient, base-e form (per day)

D_L = coefficient of molecular diffusion (ft^2/day)

S = channel slope (ft/ft)

H = hydraulic depth (ft)

The value of D_L was taken at 0.002 ft^2/day, based on stream characteristics, in which case the equation reduces to

$$k_2 = 50\ S^{0.25}\ H^{-1.25}.$$

Several channel shapes were investigated as to their effect on the reaeration coefficient. A rectangular channel was selected because actual Third Fork Creek stream banks are typically steep. The variation of k_2 with flow is shown in Figure 58 for rectangular and trapezoidal channels having the same gross cross-sectional area. Flows and

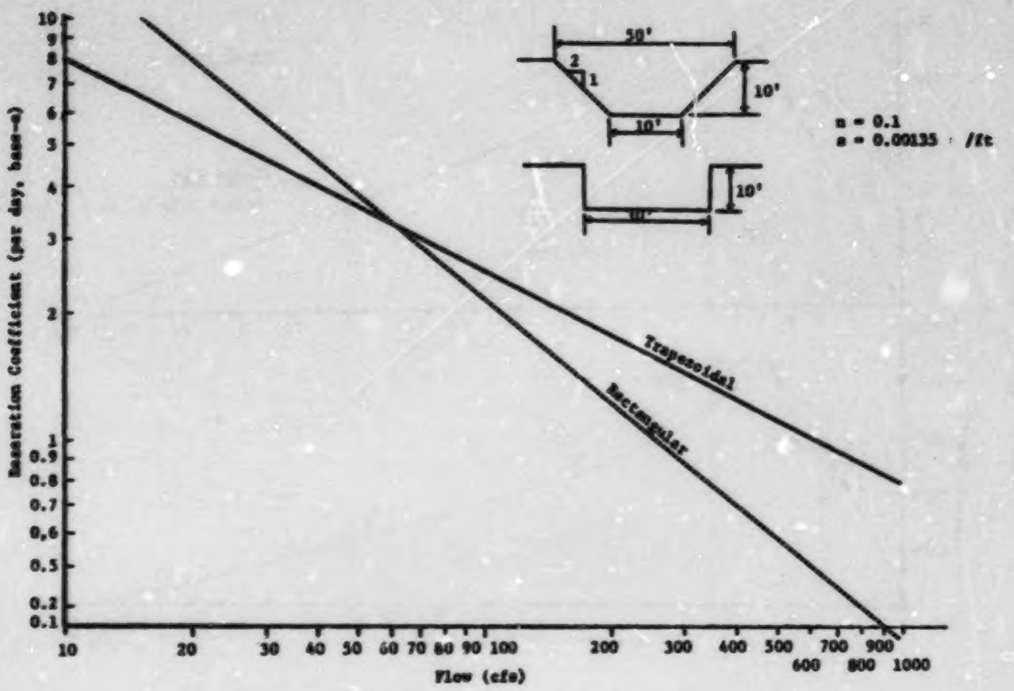


Figure 58. Effect of channel shape and flow variation on reaeration coefficient.

corresponding hydraulic depths were computed with the Manning equation using a slope of 1.35 feet per thousand feet and a roughness coefficient of 0.1, as estimated for the real stream.

In order to determine the effect of channel storage on the shape of the hydrograph, the storm wave was routed through approximately 20 miles of the stream by conventional routing methods assuming constant channel characteristics and no intervening contributory flow. The results of the routing are shown in Figure 59. The intermediate hydrograph (approximately 10 miles downstream) was used to estimate typical flow values for various components of the illustrative storm.

The illustrative storm was divided into four components for study. Each component was assumed to be completely mixed with no intermixing between component parts. The components were the first flush, the peak, the falling limb and the tail. The arbitrarily selected component boundaries are shown in Figure 57. In each case the initial ultimate BOD for the component was computed from the ratio of total pounds of BOD to total volume of water.

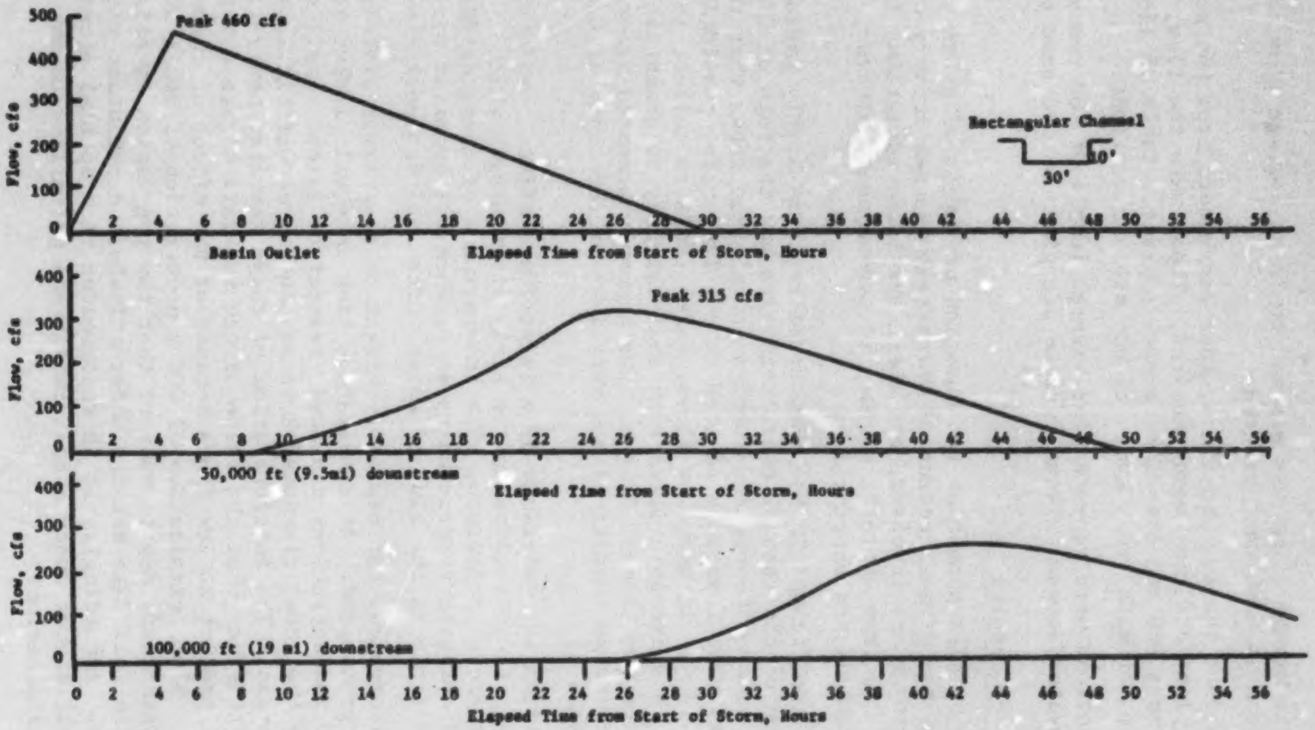


Figure 59. Effect of channel storage on storm flow downstream.

In addition to the illustrative storm described previously, a larger storm having a return period of approximately 5 years and two very small storms were modeled in a similar manner to examine the effect of storm size.

The municipal treatment plant was assumed to be at average flow, BOD and DO conditions in each case treated.

For each entry into the sag equations, four parameters from the upstream reach and the plant effluent were required. These were the flow, temperature, ultimate BOD and dissolved oxygen content. Table 22 lists the input data together with the results of the sag computations.

The sag computations were repeated for several levels of BOD removal from the stormwater stream. These results are given in the same table.

Interpretation of Results

The oxygen-sag studies show that the question of impact of urban stormwater runoff on the oxygen content of downstream reaches is very complex. Many factors are involved, and there are large variations from place to place and from storm to storm. It does appear, however, that some generalizations are appropriate.

The reaeration coefficient in the downstream reach is highly variable, being a function of the channel characteristics and the rate of flow. The previously cited O'Connor and Dobbins formulation shows that the rate of reaeration is inversely related to the flow rate, provided there is significant flow. At very low flows, water tends to collect in channel depressions and irregularities such that velocity is essentially zero over much of the channel length. The commonly accepted reaeration coefficients for these conditions are very low--of the order of 0.10 to 0.15 per day (base e).

The studies confirm the existence of a first-flush effect, evidencing higher pollutant concentrations in the early storm stages which decrease as the storm progresses. The interactions of changing BOD concentrations and changing reaeration rates produce the greatest dissolved oxygen deficit in the slug of water which includes peak flow.

As storm size increases, the depletory effect on downstream dissolved oxygen is more pronounced. At comparative time intervals larger storms have higher BOD concentrations and lower reaeration rates. Small storms are depicted by the model discussed here as causing no deficit whatever in dissolved oxygen. The interpretation of these results, however, must be tempered by the fact that the value of the reaeration rate constant is difficult to predict at low flows because of the effect of channel irregularities. Also, examination of COD concentration of small storms in the source data leads one to suspect that the regression equation obtained from the full data set may underestimate the pollutant yield of small storms. Accordingly, it is recommended that special attention be given to small storms under actual conditions prevailing in any real basin under consideration.

Table 22. RESULTS OF OXYGEN-SAG COMPUTATIONS FOR STUDY WATERSHED

Storm Type	Rainfall (in)	Duration (hr)	Return Period (yr)	Storm Component	Storm Flow (cfs)	Reaeration Coefficient (per day)	Ultimate BOD (mg/l)	Deoxygenation Coefficient (per day)	Flow Time to Sag Point (day)	D.O. Deficit at Sag Point (mg/l)	D.O. at Sag Point (mg/l)	D.O. (mg/l) at Sag Point With Stated BOD Removal from Stormwater		
												20%	40%	60%
Small Storm	0.1	1	-	Total Storm	40	4.00	40	0.12	0	0	10.0	-	-	-
Small Storm	0.1	3	-	Total Storm	20	5.70	31	0.12	0	0	10.0	-	-	-
1-2 year Storm	1.0	5	1 to 2	First Flush	200	1.25	75	0.12	2.0	5.6	4.5	5.6	6.7	7.8
				Peak	315	0.86	62	0.12	2.6	6.3	3.8	5.0	6.3	7.3
				Falling Limb	200	1.25	47	0.12	1.9	3.5	6.5	7.2	7.9	8.6
				Tail	75	2.75	37	0.12	0.8	1.4	8.7	8.9	9.1	10.0
5-year Storm	3.3	5	5	First Flush	500	0.58	85	0.12	3.4	11.7	0*	0.7	3.0	5.3
				Peak	1100	0.32	70	0.12	4.8	14.7	0*	0*	1.2	4.1
				Falling Limb	800	0.40	54	0.12	4.2	9.7	0.3	2.3	4.2	6.1
				Tail	300	0.90	42	0.12	2.4	4.1	5.9	6.8	7.6	8.4
7-day, 10-year Low Flow	-	-	-	-	0.3	0.13	15	0.12	6.0	11.9	0*	0*	0*	0*

* Anaerobic

Notes:

1. Treatment Plant Parameters for all Cases: Flow = 5.1 cfs
   BOD = 27 mg/l
   D.O. = 3.3 mg/l
2. Water temperature assumed to be 60°F.
3. Initial stormwater D.O. estimated at 9.3 mg/l based on watershed observations.

One of the principal research objectives was to ascertain the relative effects of upgrading the municipal treatment plant and of treating urban stormwater. The results from the hypothetical situation indicate that under storm flow conditions, downstream oxygen content is relatively independent of the degree of treatment at the municipal treatment plant. Oxygen-sag estimates are unchanged if the secondary treatment level in the municipal plant is upgraded to 100 percent BOD removal in the plant effluent. On the other hand, at extreme low-flow levels the downstream water quality remains unaffected by water quality upstream from the plant. Therefore, if a desired dissolved oxygen content is to be maintained downstream from the plant under storm conditions, treatment of the stormwater is necessary.

Under these study conditions and subject to the limitations of the assumptions, simplifications and local applicability, the effects of various levels of BOD removal from the urban land runoff were investigated with respect to improving the sag-point oxygen content. The results are summarized in Figure 60. This figure is not intended for design purposes, but it does indicate the degree to which treatment of stormwater might affect improvement in downstream water quality.

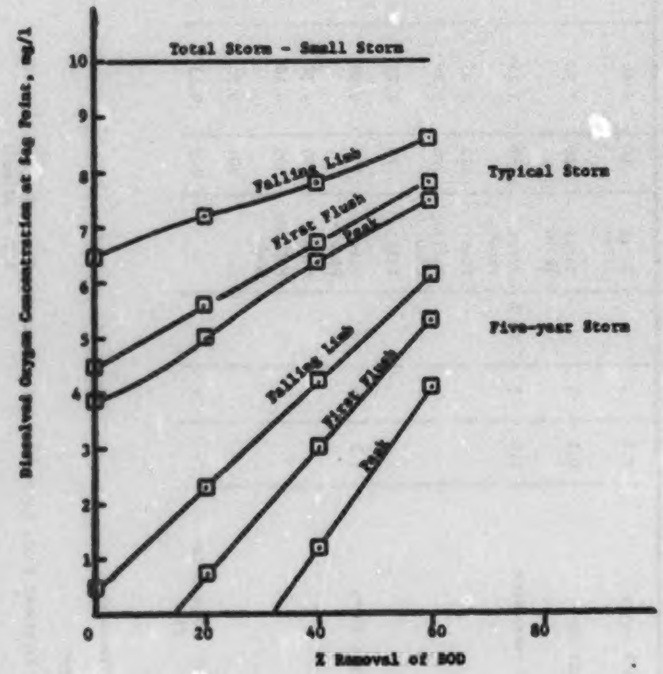


Figure 60. Effect of stormwater treatment on oxygen sag under storm conditions.

Elsewhere in this report the COD removal efficiency of plain sedimentation under quiescent settling conditions is shown to average 60 percent. Thus, significant benefits may be obtained from installation of holding ponds designed for organic removal by sedimentation. Such a facility could be usefully designed for other objectives such as reduction of flooding and entrapment of urban sediment.

The study of downstream effects described above assumed constant channel characteristics for an indefinite stream length below the discharge point. Because of the importance of the value of the reaeration rate constant, critical conditions would be suspected where urban streams discharge into nearby static bodies of water. Such conditions might be expected where large urban areas are near estuaries, such as Richmond, Virginia, or Washington, D. C., or where urban streams discharge into reservoirs.

If it is accepted that the 7-day, 10-year low flow is an appropriate design criterion for dry conditions in the stream, contravention of minimum standards would be expected on an average of once in 10 years. These hypothetical studies of the impact of urban land runoff on water quality indicate that the 5-year storm may impose more severe depletions of dissolved oxygen than the accepted dry-flow criterion. Therefore, to be consistent in overall water quality management, it appears necessary to develop concepts and criteria applying to urban stormwater runoff. While the degree of oxygen depletion may be more severe in a large storm event than in a protracted dry period, it is also of shorter duration.

Summary

The purpose of this section was impact assessment of urban runoff on water quality.

Urban runoff in the basin monitored was compared in quality and quantity to municipal waste. Municipal waste was found to have higher organic content while urban runoff contains much higher levels of suspended solids and metals. From the data collected, it may be inferred that if the City of Durham were to remove 100 percent of organics and suspended solids, the net reduction in total raw waste components would be 52 percent of the COD, 59 percent of the ultimate BOD and only 5 percent of the total suspended solids on an average annual basis. The delivery of urban runoff contaminants, however, is highly specific to wet-weather flow. During wet periods, approximately 20 percent of the time in this study, stormwater contributes 82 percent of the COD, 77 percent of the BOD, and 99 percent of the suspended solids in the potential raw waste load of the watershed.

The influence of urban stormwater on downstream dissolved oxygen content was investigated by applying oxygen-sag concepts to a hypothetical channel draining an urban watershed. At the outlet of the watershed the effluent of a secondary municipal treatment plant, which serves the same watershed, is discharged. Selected storms were routed through the channel using the COD regression equation developed earlier as a basis for estimating oxygen demand in the stream due to stormwater contaminants.

Storms were divided into four parts: the first flush, peak, falling limb, and tail. Within storms the study shows that the slug of water which includes the peak sustains the most severe downstream oxygen depletion. For comparable parts of storms, the depletory effect increases with increasing storm size. The value of the reaeration constant for the stream reach under consideration varies considerably with depth of flow, having a profound effect on the degree of oxygen depletion. During storm events, the effect of the treatment plant effluent is not detectable in oxygen-sag computations. Therefore, if improvement in minimum downstream dissolved oxygen content during wet weather is required, treatment of stormwater is necessary.

SECTION IX

FACTORS INFLUENCING STORMWATER TREATMENT ECONOMICS

Introduction

This research was primarily concerned with the characterization of urban stormwater as to quality and with investigation of alternative means of treatment. The following discussion of treatment economics necessarily touches on areas outside the project scope but which have an important bearing on final treatment cost. Consequently, these economic considerations are mainly subjective and not quantitative, consisting of suggestions of alternatives to be investigated by others as they may apply in particular circumstances.

Treatment costs may be divided into cost categories of collection, treatment, and final sludge disposal.

Collection

The nature of the existing storm-drainage system will dictate to a great extent what type of facility is best for urban stormwater treatment. In conventional domestic waste collection/treatment systems, the collection system comprises 70 to 80 percent of the cost. Where existing storm drainage is combined with the sanitary system, separation is economically inefficient by inspection if stormwater is to be treated. The accommodation of storm surges by flow equalization through storage appears to be a better choice.

The question of treatment economics is perhaps more unconstrained where separate systems exist or where none exists as in the case of a new town. Typically, in separate systems, stormwater is conveyed to the nearest natural drainage channel. In such a system, alternatives for stormwater treatment range from interception and centralized treatment to dispersed treatment along natural watercourses. Throughout this range, economics of plant size and plant density are evident.

An influence on the plant location decision is the degree to which water quality is to be assured in small streams. If, for instance, dissolved-oxygen content is to be supported in small collector streams, a larger number of small plants may be required. Alternatively, some of these streams might be enclosed in pipes to reduce the number of plants. If water quality requirements are to be in force only on those streams leaving urban areas, fewer and larger plants are indicated.

Some non-structural alternatives to plant treatment in small watersheds are feasible. In street-cleaning operations, vacuum sweeping might replace street flushing to reduce the quantity of contaminants delivered to the stream. Drainage design policies might be changed to exploit the storage and natural percolation capacities of the watershed. This could be accomplished by minimizing piped flow in areas such as parks, and by causing drainage to occur in sheet flow through vegetated strips.

It is evident that the outcome of considerations mentioned above will constrain plant size and type. Conversely, the plant cost function, practical size limitations, and land availability will determine to some degree the needs of the stormwater collection system.

Treatment

Given that the drainage area and stormwater quality characteristics are set, a range of alternatives exist for treatment, depending on required effluent quality.

It has been demonstrated earlier that plain sedimentation will remove approximately 60 percent of the COD under quiescent conditions. This fact, coupled with the observation that reduction in downstream flow rate could be expected to increase the reaeration rate, suggests that simple storage of the entire or early fraction of the storm wave might significantly improve water quality under certain circumstances. Preliminary estimates indicate that a holding pond of 20 acre feet per square mile of drainage basin would reduce the peak outflow of a 5-year storm to one-half the peak inflow. The downstream reaeration rate would be about 70 percent higher as a result of the flow reduction, depending on channel characteristics. The settling efficiency of such a storage pond is estimated to vary from about 30 percent removal of COD, at peak flow of the 5-year storm, to approach 60 percent removal at lower flows. Whether such a facility can satisfactorily improve urban water quality is dependent on stream standards, hydraulic and pollutional loading of the facility, and characteristics of the downstream reach. If a large number of small facilities are contemplated, temporary storage and simple sedimentation are feasible. Additional benefits accrue from the reduction of urban flood peaks and from the entrapment of urban sediment.

The physical-chemical process of coagulation-sedimentation appears to be an economical treatment method if plain sedimentation is not sufficient. A typical installation might consist of a detention pond to hold that fraction of the storm wave having the highest level of contamination and a treatment facility for the operations of chemical feed, flash mix, flocculation, and sedimentation. It may be readily observed that an economic trade-off exists between the size of the storage pond and the flow capacity of the treatment facility, given the nature of the design storm. Thus, land cost would be expected to be a strong influence on economic plant size. Elsewhere in this report are discussions and recommendations regarding specific coagulating agents.

Sludge Disposal

The high turbulence of flowing stormwater supports its high suspended solids content. So anywhere that stormwater is slowed and detained, sediment will accumulate. This effect would be exploited in a system of ponds for simple sedimentation. The sediment to be removed from such a pond would consist primarily of relatively coarse materials. Removal could be effected by draining the pond, allowing the deposits to dry and excavating them by ordinary earth-moving procedures. Material thus taken may be disposed of as low-quality fill. Since it would be highly erodible, it should be stabilized. It can be beneficially used as daily cover in a sanitary landfill.

Where stormwater treatment beyond simple sedimentation is undertaken, the sludge disposal problem is more severe. The sludge which results from the flocculation operation is light and fluffy. Dewatering difficulties would be expected, and ultimate disposal would be subject to the same considerations as in municipal treatment plants.

Summary

The question of treatment economics was investigated and determined to be highly sensitive to such local parameters as the nature of quality standards, the nature of existing stormwater collection and disposal, and the degree of treatment required. The data collected within the scope of this project does not permit detailed economic analysis of alternative treatment decisions. The principal contribution of this research to the question of treatment economics lies in the quantification of pollutional and hydraulic loadings which will serve as part of the data base for analysis by others in relation to project development in specific watersheds.

SECTION X

EVALUATION OF EPA STORM WATER MANAGEMENT MODEL

Introduction

One objective of the project was to evaluate the effectiveness of EPA's Storm Water Management Model (SWMM) (7) in predicting the quality and quantity of runoff from the Third Fork Creek drainage basin. Four storm events were modeled for comparison with the main gaging site observations and two at sub-basin N-2. The model is designed to simulate urban stormwater runoff phenomena with quality and quantity being the descriptors. The model's primary objective is to give engineers a tool with which to assess, evaluate, and control problems associated with excess urban surface waters.

The SWMM Model

The Storm Water Management Model uses a high-speed digital computer to simulate real storm events on the basis of rainfall (hyetograph) inputs and system (catchment, conveyance, storage/treatment, and receiving water) characterization to predict outcomes in the form of quantity and quality of runoff. The simulation technique--that is, the representation of the physical systems identifiable within the model--was selected since it permits relatively easy interpretation, location of remedial devices (such as a storage tank or relief lines), and/or denotes localized problems (such as flooding) at a great number of points within the physical system. The SWMM program objectives are particularly directed toward complete time and spatial effects, as opposed to simple maxima (i.e., rational formula approach) or only gross effects (i.e., total gross pounds of pollutant).

In simplest terms the program is built up as follows:

1. The input sources:

   RUNOFF generates surface runoff based on an arbitrary rainfall hyetograph, antecedent conditions, land use, and topography.

   FILTH generates dry weather sanitary flow based on land use, population density, and other factors.

   INFIL generates infiltration into the sewer system based on available groundwater and sewer condition.

2. The central core:

   TRANS carries and combines the inputs through the sewer system in accordance with Manning's equations and continuity; it assumes complete mixing at various inlet points.

3. The correctional devices:

   TSTRDT, TSTCST, STORAG, TREAT, and TRCOST modify hydrographs and pollutographs at selected points in the sewer system, accounting for retention time, treatment efficiency, and other parameters; associated costs are computed also.

4. The effect (receiving waters):

   RECEIV routes hydrographs and pollutographs through the receiving waters, which may consist of a stream, stream bed, lake or estuary.

The quality constituents simulated by the model are the 5-day BOD, total suspended solids, total coliforms (represented as a conservative pollutant), and dissolved oxygen.

Program Blocks

The adopted programming arrangement consists of a main control and service block, the Executive Block, and four computational blocks: (1) Runoff Block, (2) Transport Block, (3) Storage Block, and (4) Receiving Water Block.

The Executive Block assigns logical units (disk/tape/drum), determines the block or sequence of blocks to be executed, and, on call, produces graphs of selected results on a line printer. Thus, this Block does no computation as such while each of the other four blocks are set up to carry through a major step in the quantity and quality computations. All access to the computational blocks and transfers between them must pass through sub-routine MAIN of the Executive Block. Transfers are accomplished on off-line devices (disk/tape/drum) which may be saved for multiple trials or permanent record.

The Runoff Block computes the stormwater runoff and its characteristics for a given storm for each sub-catchment and stores the results in the form of hydrographs and pollutographs at inlets to the main sewer system.

The Transport Block sets up pre-storm conditions by computing dry weather flow and infiltration. The block then performs its primary function of flow and quality routing by picking up runoff at various input locations and producing combined flow hydrographs and pollutographs at intermediate points and for the total drainage basin.

The Storage Block uses the output of the Transport Block and modifies the flow and characteristics at a given point or points according to the predefined storage and treatment facilities provided. Costs associated with the construction and operation of the storage/treatment facilities are computed.

The Receiving Water Block accepts the output of the Transport Block directly or the modified output of the Storage Block and computes the dispersion and effects of the discharge in the receiving river, lake or bay.

General Data Requirements

A generalized listing of data requirements prior to the use of the program are given on the following page:

ITEM 1. Study Area Definition

Land use, topography, population distribution census tract data, aerial photos, area boundaries.

ITEM 2. System Definition

Acquire plans of the collection system to define branching, sizes, and slopes. Types and general locations of inlet structures.

ITEM 3. Define System Specialties

Flow diversions, regulators, storage basins.

ITEM 4. Define System Maintenance

Street sweeping (description and frequency). Catchbasin cleaning. Trouble spots (flooding).

ITEM 5. Define the Receiving Waters

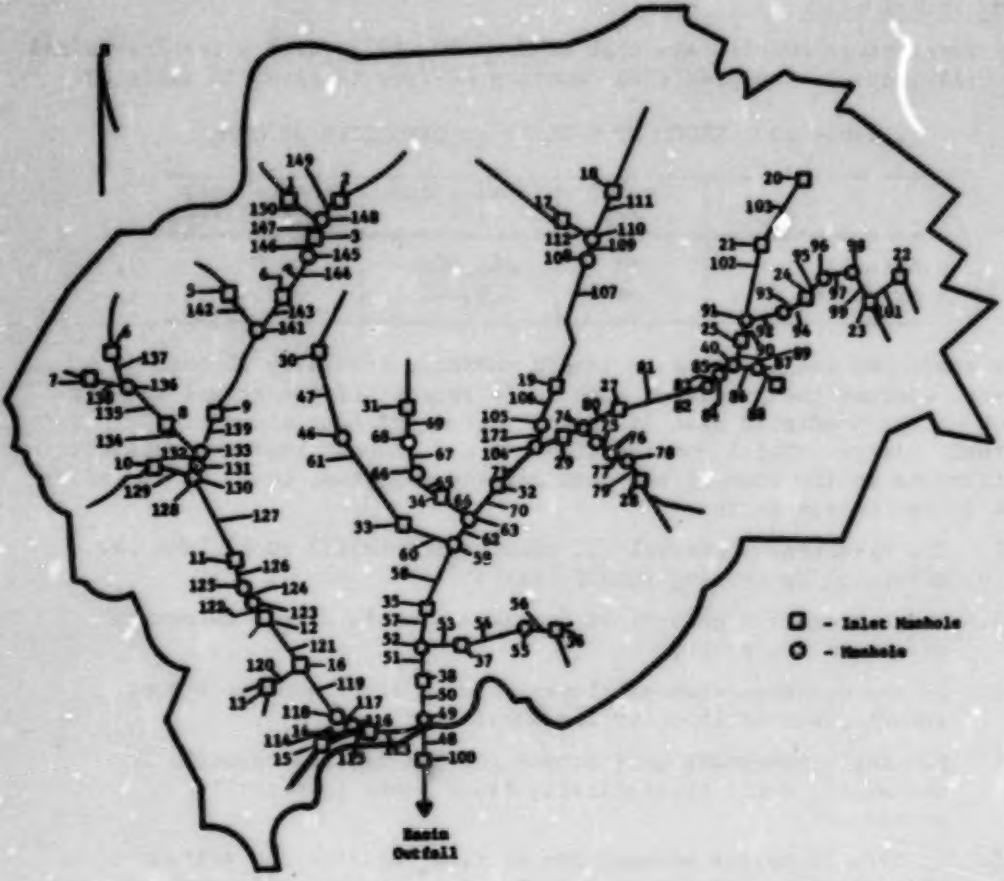
General description (estuary, river, or lake). Measured data (flow, tides, topography, water quality).

Application to Third Fork Creek Drainage Basin

Data for the purpose of modeling the drainage basin was obtained principally from the Durham Department of Public Works. Topographical, land use, and storm sewer maps contained the bulk of the data, supplemented with street cleaning data. Aerial photos were obtained from the North Carolina State Highway Commission. Also, several days of on-site investigation were necessary to determine cross-sectional area of man-made and natural conduits, catchbasin density, and data verification.

With data collection complete and with the intent to make each subcatchment representative of a dominate land use, discretization was accomplished. However, the intention was not fully realized, as many of the 38 subcatchments had to be defined on the basis of drainage area instead of land use. Integrated land uses and the natural drainage channel network made any other division unrealistic. Figure 61 indicates the subcatchment boundary arrangement with respective numbers. The subcatchments were then subdivided into 119 subareas by totaling the acreage within the subcatchments for each of the five available land uses within SWMM. Subcatchment and subarea data were collected as prescribed by Volume III - The User's Manual (7).

The Third Fork Creek Basin stormwater drainage system is a combination of gutters and pipes which empty into natural drainage channels. The modeled drainage system is shown in Figure 61. Gutters and pipes in the Runoff Block are not numbered due to a lack of space. Fifty gutters and/or pipes were modeled for the Runoff Block while 146 manholes and conduits were modeled for the Transport Block. Manholes were placed in the system whenever conduit cross-sectional area changed, a change in slope occurred, and/or at conduit junctions. Element No. 19 represents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Basin Outfall
□ - Inlet Manhole
○ - Manhole

Figure 61. SWMM map of Third Fork Creek system.

the outfall for the North-2 sub-basin with Element No. 100 being the entire basin's outfall.

Only in those places where piping became necessary (e.g., under streets, Central Business District, etc.) were conduits well defined hydraulically. Man-made conduit shapes presented no problems; however, natural channels with constantly changing cross-sections presented a definite problem in specifying an equivalent man-made shape. Natural channels were approximated as semi-circular. Difficulties were experienced in characterizing roughness coefficients in natural channels. Roughness coefficients ranged from 0.03 to 0.09 for natural channels.

SWMM Verification

The first storm modeled was that of June 20, 1972, with a total rainfall of 0.24 inches. The predicted quantity of flow is given in Table 23.

Table 23. STORM OF 6/20/72 AS PREDICTED BY SWMM

	Peak Q CFS	Total volume ft^3	Time of peak military time
Actual	75	263,000	0810
Predicted	54	276,000	0720

The predicted total volume of runoff compares favorably (5 percent error) whereas the predicted peak is 72 percent of the actual and the time of the predicted peak is approximately one hour ahead of the actual. After careful consideration it was thought that the apparent difference in the time of the peak and the magnitude could be caused by the following six factors:

1. The hyetograph interval (10 minutes initially) could have the effect of decreasing runoff peaks;
2. The integration period, if too large, could have a dampening effect on the peaks;
3. If the drainage channel slopes were in error and too steep, runoff peaks would occur too soon;
4. Manning's roughness coefficient for the natural channel, if too small, could theoretically cause peaks to occur prematurely;
5. If default values assumed for surface infiltration calculation did not approximate actual values, volumes of total gutter flow (computed vs. recorded) would be different; and
6. If default values assumed for surface runoff resistance (0.25) in previous areas were low, computed peak runoff would tend to occur before the actual occurrence.

A check of Table 23 reveals little difference in the total volume of computed gutter flow as compared to the recorded value. Therefore, the assumed default values for surface infiltration were considered correct. A recheck of drainage channel slopes indicated no changes had to be made. Factors 1, 2, 4, and 6 were tested to see what effect an error or change in data would have.

First, a series of four modeling runs were made to see what effect changes of hyetograph intervals and integration periods would have on the June 20, 1972, storm. The following cases were tested:

	Case 1	Case 2	Case 3	Case 4
Integration Period, min.	10	5	5	3
Hyetograph Interval, min.	10	5	2.5	2.5

Each case was analyzed by hydrograph comparisons. Results of the analysis are given in Table 24.

Table 24. EFFECT OF VARYING INTEGRATION PERIOD AND HYETOGRAPH INTERVAL ON DISCHARGES AS PREDICTED IN SWMM ON THE STORM OF 6/20/72

	Computed vs. recorded percent error		Computed vs. recorded
	Peak discharge	Total discharge	time of peak difference
Case 1	- 28%	+ 5%	50 min. lead
Case 2	- 11%	+ 23%	45 min. lead
Case 3	- 27%	0%	50 min. lead
Case 4	- 17%	- 5%	50 min. lead

None of the above changes produced significantly better comparisons. Hence, all verification was conducted with a 5.0 minute integration period and a hyetograph interval of 5.0 minutes.

Secondly, natural channel roughness coefficients were changed. After reviewing conditions of the natural stream channels, a substantial number of roughness coefficients were raised to 0.09. The time differential was not changed at all, and the peak runoff was virtually unchanged as a result of raising roughness coefficients.

Lastly, the surface resistance factor was modified. Initially, the default value of 0.25 was used, and the change was to a value of 0.35 for all previous areas. Again, no difference was observed in the computed output.

Verification testing was then resumed using a 5-minute integration period and hyetograph interval and default values for surface resistance.

A total of four storms were modeled and compared in the verification tests. Modeled storm dates and characteristics are listed as follows:

Storm date	Volume of rainfall, in.	Duration, hr.
6-20-72	0.24	7.50
8-28-72	0.06	2.25
9-21-72	0.50	9.66
10- 5-72	2.10	7.50

Two sampling locations were used in verification testing. Storm data from the main gaging station in the USGS station (inlet No. 100) was compared for each storm. Sub-basin North-2 data were compared for the storm events occurring on dates 6-20-72 and 10-5-72. Computed/modeled outflow hydrographs and pollutographs for the North-2 sub-basin come from the modeled inlet No. 19.

Evaluation of Predicted Quantities of Runoff

Figures 62 through 65 give rainfall hyetographs with SWMM predicted versus recorded hydrographs for the basin outfall. The storm occurring on 9/21/72 appears to have a good fit timewise. Even then, computed and recorded peak discharges are significantly different. The comparison of peak flows, total volume, and time of peak for the main gaging station are presented in Table 25.

Table 25. COMPARISON OF PREDICTED PEAK FLOWS, TOTAL GUTTER FLOWS, AND TIME OF PEAKS FOR THE FOUR STORMS MODELED

	Peak runoff		Total gutter flow		Time of peak	
	cfs	% Error	ft^3	% Error	24 hr. clock	Difference
6-20-72 COMPUTED	67	11	309430	17	0720	50 min. lead
RECORDED	75		263738		0810	
8-28-72 COMPUTED	6.7	56	29978	89	1110	55 min. lead
RECORDED	4.3		15780		1205	
9-21-72 COMPUTED	59	40.5	594778	198	0840	15 min. lead
RECORDED	42		199534		0855	
10-5-72 COMPUTED	425	51	3115659	59	1135	35 min. lead
RECORDED	870		7572000		1210	

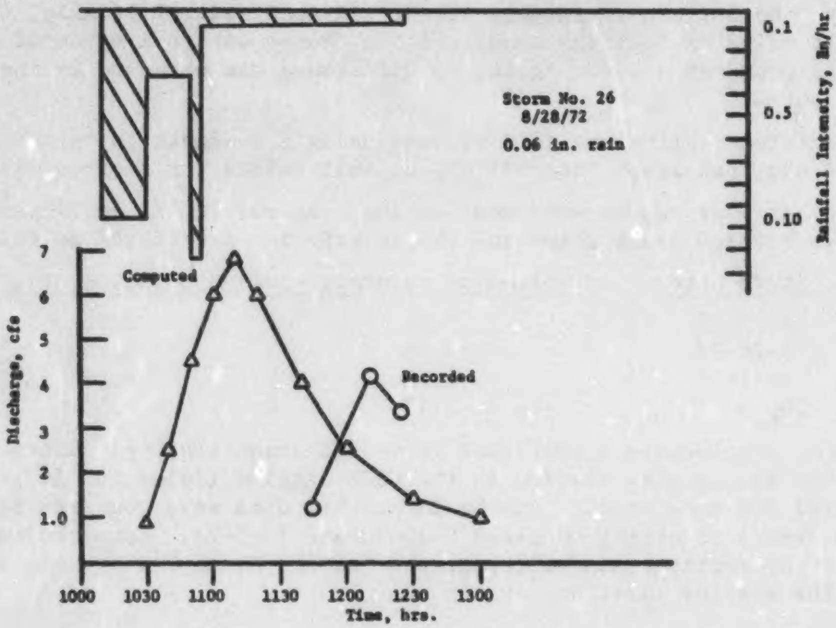

Figure 62. Modeled vs. recorded hydrograph for USGS main gaging station with associated hyetograph.

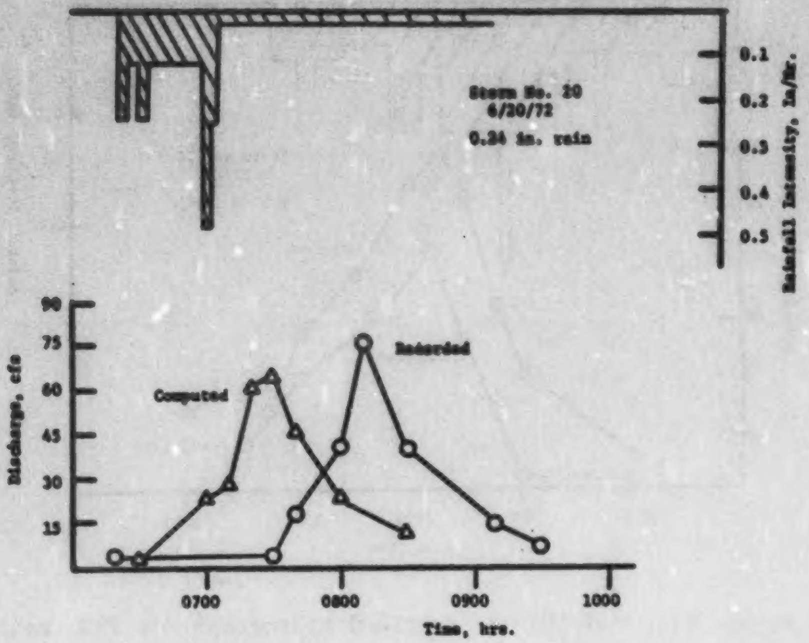

Figure 63. Modeled vs. recorded hydrograph for USGS main gaging station with associated hyetograph.

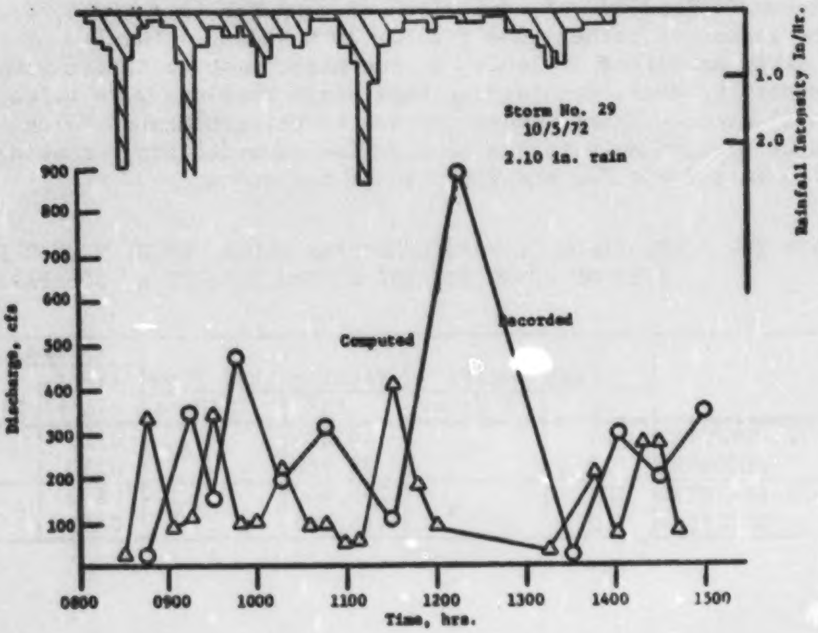

Figure 64. Modeled vs. recorded hydrograph for USGS main gaging station with associated hyetograph.

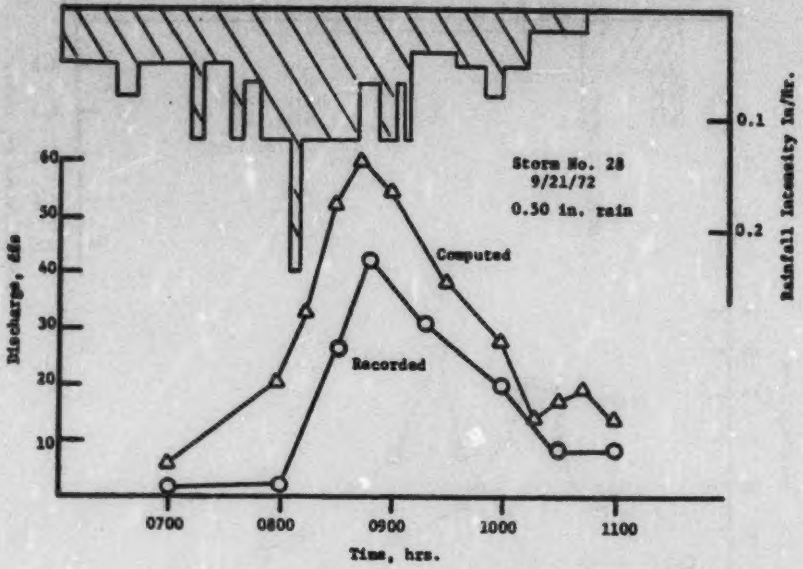

Figure 65. Modeled vs. recorded hydrograph for USGS main gaging station with associated hyetograph.

Computed and recorded outflow hydrographs for the North-2 sub-basin are in Figures 66 and 67. A comparison of computed versus recorded hydrographs reveals a rather good fit for both storms. In view of the percent error as listed in Table 26, one might wish to differ with that statement; however, considering that stage readings were taken manually 20 to 30 minutes apart, there appears to be agreement. Values in Table 26 pertain only to the time period recorded stage readings that were taken and not for the duration of the storm.

Table 26. COMPARISON OF PREDICTED PEAK FLOWS, TOTAL GUTTER FLOWS AND TIME OF PEAKS FOR THE STORMS MODELED AT SUB-BASIN N-2

	Peak runoff		Total gutter flow		Time of peak	
					24-hr. clock	
	cfs	% Error	ft^3	% Error		Difference
6-20-72 COMPUTED	24	30	40,200	47	0710	20 min. lead
RECORDED	18.5		75,780		0730	
10-5-72 COMPUTED	107	5	295,200	30	0840	10 min. lead
RECORDED	102		416,400		0850	

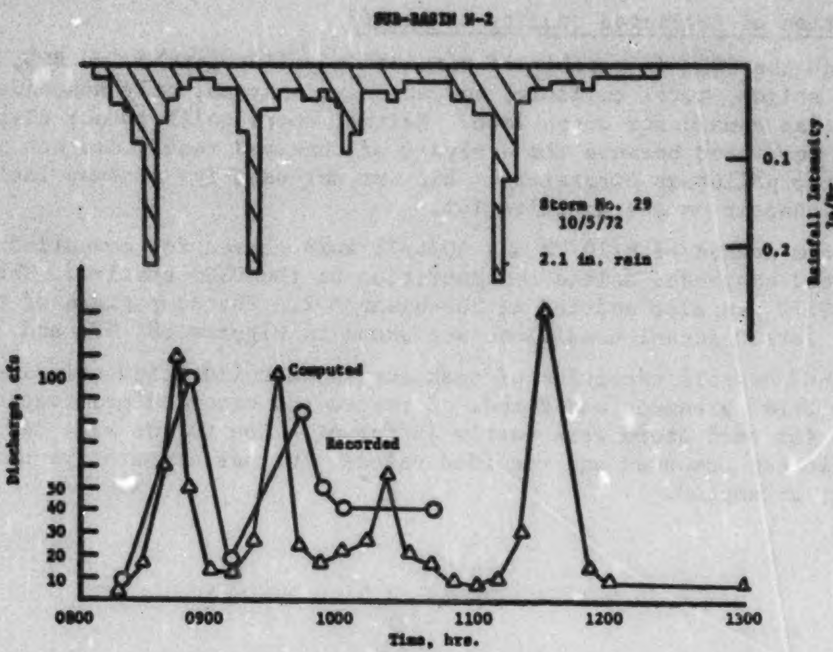

Figure 66. Modeled vs. recorded hydrograph for Sub-basin North-2 with associated hyetograph.

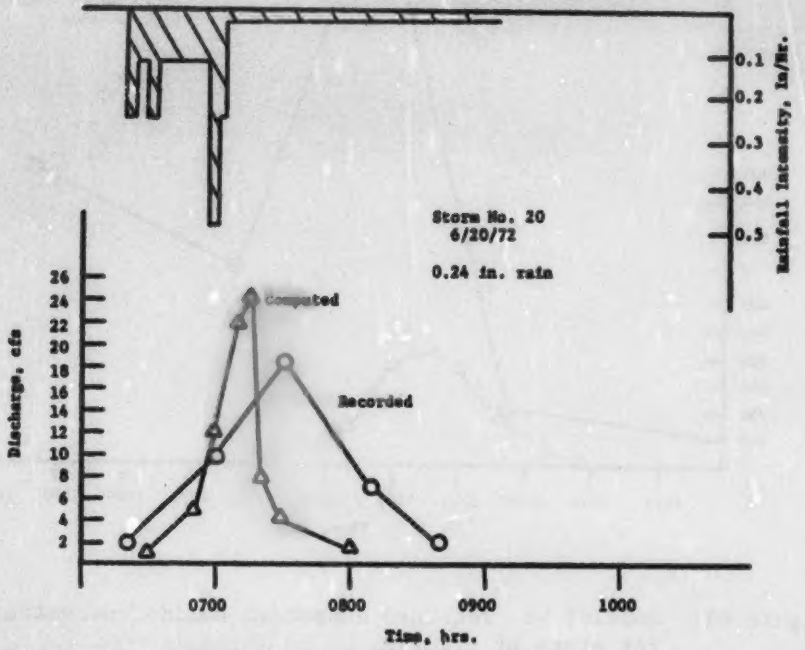

Figure 67. Modeled vs. recorded hydrograph for Sub-basin North-2 with associated hyetograph.

Evaluation of Predicted Quality of Runoff

Although the SWMM is capable of simulating pollutographs for BOD, suspended solids, total coliform, and dissolved oxygen, only suspended solids was chosen for comparison. Neither total coliform nor dissolved oxygen were used because the analysis of observed runoff did not include those two pollutant parameters. BOD was not used for reasons included in the chapter on characterization.

The storm events of 6/20/72 and 10/5/72 were chosen for comparison of predicted suspended solids concentration at the USGS station. The storm of 6/20/72 was also modeled at Sub-basin N-2. The comparison of predicted versus actual conditions are shown in Figures 68, 69, and 70.

With the possible exception of peak suspended solids time coincidence, very little agreement was found. Computed and recorded peak suspended solids for each storm were vastly different. Due to the wide differences in the computed and recorded values, further comparative analysis was not attempted.

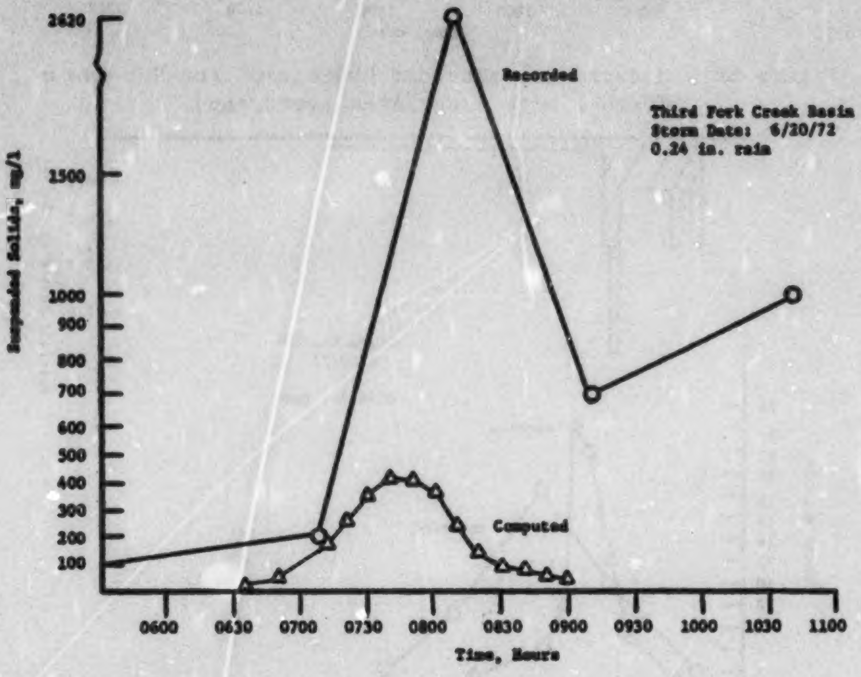

Figure 68. Modeled vs. recorded suspended solids concentration for storm of 6/20/72.

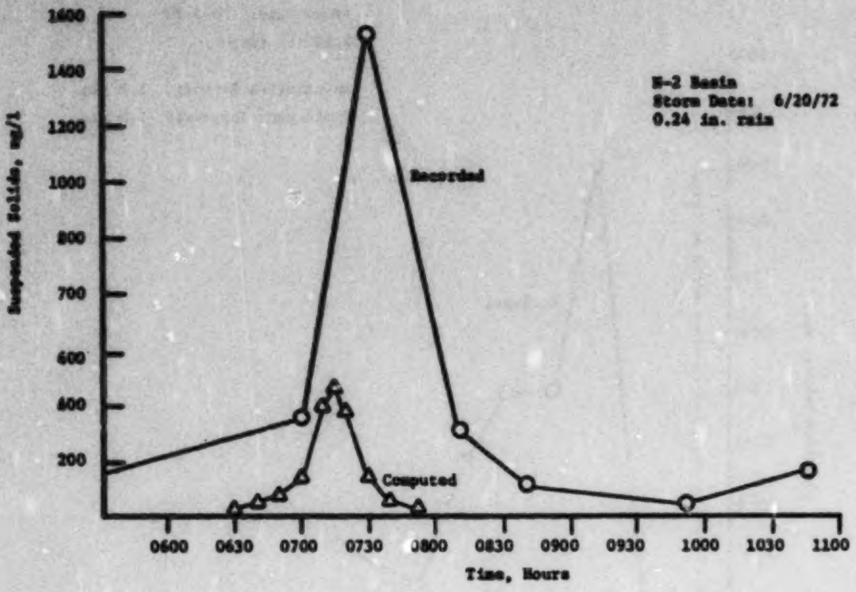

Figure 69. Modeled vs. recorded suspended solids concentration for storm of 6/20/72.

Summary

As a result of modeling four actual storm events with the Storm Water Management Model in Durham, North Carolina, it appears that:

1. The total volume of discharge as predicted by the model appears to be within an acceptable range of the actual measurements.
2. The predicted time of peak discharge is approximately 40-50 minutes ahead of that measured for the 1.67 square-mile drainage basin.
3. The predicted peak discharge is less than that measured in the field for the total basin.
4. The time and peak discharge is approximated better by the model for situations involving man-made conduits than it is for situations involving natural channels.
5. The flux of suspended solids as predicted by the model is substantially less than that observed in the field.

On the basis of the experience gained with the model in Durham, North Carolina, it is recommended that:

1. The limit of 160 sewer elements in the transport block be increased.

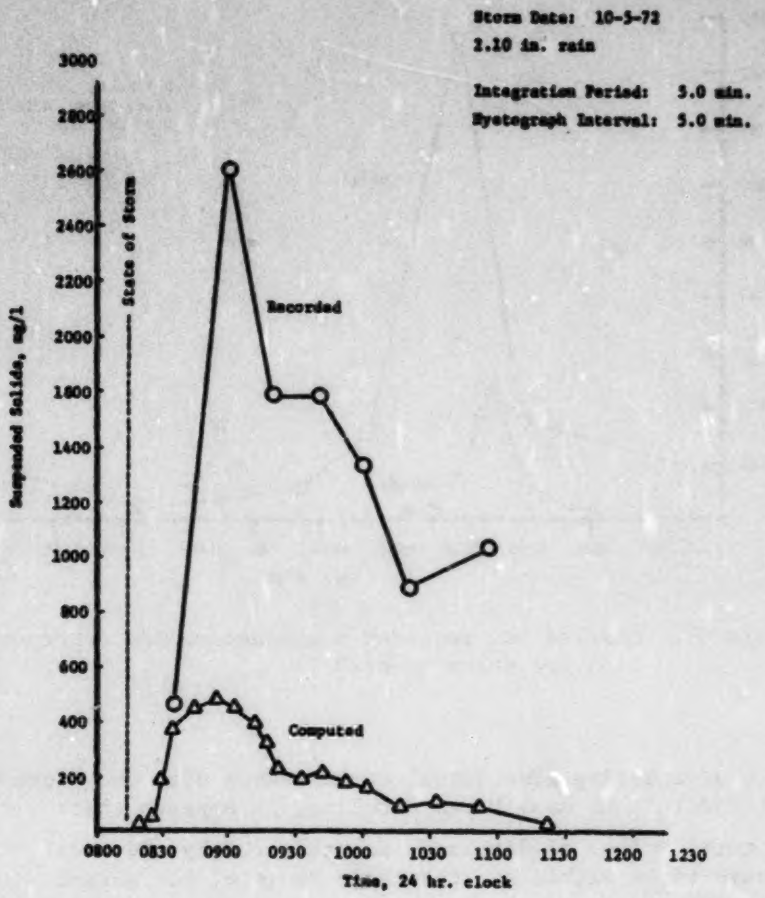

Figure 70. Modeled vs. recorded suspended solids concentration for storm of 10/5/72 at USGS station.

2. Consideration be given to the inclusion of additional types of land use classifications such as expressways, construction sites, and large parking lots.
3. A natural drainage channel shape be included in the list of man-made conduit shapes.
4. The functions generating suspended solids concentrations need additional refinement.

SECTION XI

REFERENCES

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SECTION XII

GLOSSARY

GENERAL

CFS - Cubic feet per second
EPA - Environmental Protection Agency
GPD - Gallons per day
GPM - Gallons per minute
HRS - Hours
MG/L - Milligrams per liter
NC - North Carolina
Q - Discharge rate
SWMM - EPA Storm Water Management Model
USGS - United States Geological Survey
°C - Degrees centigrade
#/ml - Number per milliliter

CHEMICAL

Al - Aluminum
ALK - Alkalinity
BOD - Biochemical Oxygen Demand
Ca - Calcium
Co - Cobalt
COD - Chemical Oxygen Demand
Cr - Chromium
Cu - Copper
Fe - Iron
FC - Fecal Coliform
JTU - Jackson Turbidity Units
K-N - Kjeldahl Nitrogen
Mg - Magnesium
Mn - Manganese
Ni - Nickel
Pb - Lead
Sr - Strontium
SS - Suspended solids
TOC - Total Organic Carbon
Total-P - Total Phosphorus
TS - Total Solids
VS - Total Volatile Solids
VSS - Volatile Suspended Solids
Zn - Zinc

SECTION XIII

APPENDIX

Page

Time Parameters and Analytical Results of Urban Runoff Events Number 1 through 36 120-146

Third Fork Creek Base Flow Observations at USGS Gage House and Sub-basins 147-152

Time Parameters and Analytical Results of Urban Runoff Events Monitored at Sub-basin Discharge Locations 153-157

Table 27. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 1

Date: 10/23/71

Time (hrs) From			Q CFS	Organics mg/l		Nutrients mg/l		Solids mg/l		Metals			
Storm Start	Last Storm	Last Peak		COD	BOD	K-N	Total P	Total	SS	Co	Cu	Fe	Zn
13.0	91	1.0	111	7		.80	.22	234	160	.37	.39	5.6	.14
13.2	91.2	1.2	88	14	8	.89	.24			.35	.39	6.2	.10
13.5	91.5	1.5	78		5	.93	.28	221	115	.45	.49	5.0	.15
13.8	91.8	1.8	58	14	5	1.00	.28			.43	.50	6.0	.11
14.0	92	2.0	58	14	20	.99	.28	215	40	.42	.34	6.4	.13
14.2	92.2	2.2	66	6	2	1.09	.26			.44	.28	3.6	.60
14.5	92.5	2.5	65	12		.82	.40	281	95	.41	.38	3.5	.90
14.8	92.8	2.8	67	28	3	.87	.28			.33	.40	5.2	.11
15.0	93	3.0	66	32		.86	.26	201	85	.47	.48	3.2	.10
15.2	93.2	3.2	52	36	42	.94	.26			.17	.13	3.2	.60
15.5	93.5	2.5	44	48	25	.82	.38	196	45	.44	.23	3.0	.11
15.8	93.8	3.8	36	36	21	.77	.29			.37	.45	3.9	.70
16.0	94	4.0	31	36	30	1.02	.28	221	90	.21	.39	3.2	.11
16.2	94.2	4.2	25	36	14	1.01	.26			.23	.34	2.9	.15
16.5	94.5	4.5	23	40	33	.94	.28	241	80	.41	.58	4.5	.14

Table 28. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 2

Date: 11/24/71

Time (hrs) From			Q CFS	Organics mg/l		Nutrients mg/l		Solids mg/l		Metals							
Storm Start	Last Storm	Last Peak		COD	TOC	K-N	Total P	Total	SS	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
.1	506	506	.5	168	47	8.2	.94	430	50	.15	.27	.13	2.5	.58	.25	.41	.16
.2	506	506	.8	264	48	12.0	1.14			.20	.43	.18	5.0	.84	.15	.40	.31
.3	507	507	.9	244	55	8.6	.72	505	105	.07	.31	.18	3.2	.64	.13	.48	.21
.4	507	507	8.5	316	27	9.6	.60	555	180	.05	.25	.08	2.7	.61	.15	.38	.21
.7	507	507	9	232	60	10.2	.52	470	115	.11	.25	.15	3.5	.69	.22	.40	.21
1.0	507	537	9.8	276	58	8.6	.53	380	280	.10	.25	.12	2.4	.63	.20	.73	.17
1.2	508	508	18	392	89	7.0	.54	850	630	.06	.45	.16	4.8	.65	.12	.48	.23
1.3	508	.2	18	256	45	8.4	.58	555	365	.08	.32	.13	3.3	.64	.12	.40	.19
1.6	508	.4	14	284	46	7.9	.60	765	475	.10	.38	.20	4.1	.52	.16	.60	.23
1.7	508	.3	13	277	77	8.4	.44	445	300	.06	.30	.10	3.3	.42	.15	.44	.17
1.8	509	.7	13	169	38	8.4	.48	425	235	.15	.23	.12	3.2	.57	.21	.45	.13
1.9	509	.8	13	191	40	10.8	.45	345	225	.04	.33	.12	4.0	.45	.16	.50	.20
1.9	509	.8	13	310	46	11.6	.36	345	330	.14	.38	.13	3.6	.52	.09	.72	.15

Table 29. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 3

Date: 12/16/71

Time (hrs) From			Q	Organics mg/l		Nutrients mg/l		Fecal Coliforms	Solids mg/l		Metals mg/l								pH
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	K-N	Total P	#/ml	Total	SS	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	
.1	97.2	97.2	1	157	47	7.2	.48	505	810	305	.06	.42	.12	7.7	1.24	.22	.48	.35	6.9
.25	97.3	97.5	1	112	32	10.4		440			.09	.46	.15	5.0	1.13	.17		.33	7.0
.5	97.6	97.8	2	134	27	8.0	.4	232	730	175	.17	.42	.13	5.3	.80	.15	.40	.23	7.0
.75	98	98	2	112	28	10.8	.46	151			.10	.29	.13	3.6	.69	.17	.46	.18	7.0
1.0	98.2	98.2	3	99	23	7.6	.5	111	400	100	.04	.27	.09	3.4	.44	.20	.30	.15	7.0
1.25	98.3	98.5	3	96	25	5.7	.42	145			.13	.33	.06	2.8	.32	.22	.42	.13	7.0
1.5	98.8	.2	2	80	27	6.8	.43	145	410	95	.06	.32	.07	2.4	.60	.13	.43	.12	6.9
1.75	99	.5	2	99	30	6.8	.32	110			.11	.18	.13	2.4	.57	.19	.32	.11	6.9
2.0	99.2	.8	2	115	27	19.0	.37	90	425	140	.05	.29	.12	2.9	.60	.11	.37	.11	7.0
2.25	99.3	1.0	2	109	30	13.0	.56	100			.08	.35	.10	2.2	.58	.13	.36	.09	7.0

Table 30. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 4

Date: 12/20/71

Time (hrs) From			Q	Organics mg/l		Nutrients mg/l		Fecal Coliforms	Metals mg/l							
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	K-N	Total P	#/ml	Co	Cr	Cu	Fe	Ni	Mn	Pb	Zn
8.5	81.0	.5	23	220	42	7.6	.55	235	.11	.44	.18	11.4	.11	.79	.70	.53
8.7	81.2	.7	22	234	33	17.8	.20	425	.20	.28	.18	12.9	.15	.71	.58	.35
8.8	81.3	.8	19	216	54	7.6	.65	565	.05	.29	.17	10.6	.17	.85	.60	.43
9.0	81.5	1.0	17	176	28	14.8	.70	465	.22	.37	.18	14.6	.19	.78	.50	.31
9.3	81.8	1.3	11	230	42	13.2	.33	490	.17	.18	.09	9.3	.17	.49	.50	.26
9.7	82.2	1.7	9	154	39	6.6	.45	505	.17	.39	.12	7.3	.19	.53	.44	.27
10.0	82.5	2.0	7	194	28	9.3	.50	480	.10	.28	.11	6.9	.20	.55	.50	.25
10.3	82.8	2.3	7	154	28	6.2	.45	395	.14	.22	.16	6.9	.17	.53	.50	.32
10.7	83.2	2.7	7	183	28	7.2	.34	310	.19	.31	.14	11.4	.21	.44	.40	.29
11.0	83.5	3.0	8	183	38	7.4	.50	375	.17	.31	.11	6.8	.22	.60	.50	.30
11.3	83.8	3.3	16	216	38	13.2	.60	280	.21	.38	.12	8.0	.15	.65	.56	.40
11.7	84.2	3.6	15	128	39	12.8	.40	425	.11	.30	.12	13.6	.18	.48	.54	.27
12.0	84.5	.3	12	100	27	7.8	.48	540	.14	.27	.11	10.7	.29	.59	.45	.18
12.3	84.8	.7	11	115	37	8.8	.46	310	.16	.38	.14	14.7	.17	.63	.70	.37
12.7	85.1	1.0	11	127	34	9.2	.63	290	.14	.28	.18	9.9	.15	.53	.68	.33
13.0	85.5	1.3	11	111	41	5.4	.35	285	.06	.30	.11	14.3	.22	.60	.46	.30

Table 31. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 5
Date: 1/4/72

Time (hrs) From			Q CFS	Organics mg/1			Nutrients mg/1		Fecal Coliforms	Solids mg/1		Metals mg/1							pH
Storm Start	Last Storm	Last Peak		COD	TOC	BOD	K-N	Total P	#/ml	Total	SS	Ca	Cr	Fe	Mg	Mn	Pb	Zn	
.5	115	115	6	200	66	26			235			8.69	.27	9.5	12.0	.81	.90	.36	7.04
.8	115.3	.1	25	320	109	42*	1.6	1.2	150	920	690	5.63	.34	15.5	21.8	1.15	.88	.63	6.89
1.3	115.8	.5	13	228	43	28	1.3	2.5	895	645	550	2.89	.27	13.4	11.1	.81	.85	.45	6.77
2.4	116.9	1.6	14	144	25	14			315			2.13	.27	11.6	10.9	.52	.49	.31	7.00
2.7	117.2	1.9	11	120	11	18	1.2	.65	635	415	280			8.8		.52	.54	.28	6.85
3.1	117.6	2.3	8	84	10	18			495			3.44	.3	7.1	7.3	.42	.41	.22	6.81
3.4	117.9	2.6	6	104	14	4**	1.2	.37	270	355	190	3.36	.24	8.4	8.2	.46	.42	.25	7.33
3.7	118.2	2.9	5	92	31	7			330			4.05	.28	7.0	8.2	.44	.49	.21	7.23

* Less than 1.5 mg/1 D.O. remaining

** Less than 1.0 mg/1 D.O. uptake

Table 32. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 6
Date: 1/10/72

Time (hrs) From			Q	Organics mg/1			Nutrients mg/1		Fecal Coliforms	Solids mg/1		Metals mg/1						
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD	K-N	Total P	#/ml	Total	SS	Ca	Cr	Fe	Mg	Mn	Pb	Zn
2.0	13.0	13.0	16	140	30	7	1.6	.76	850	610	460	2.77	.29	9.9	9.1	.54	.53	.26
2.3	13.3	13.3	20	152		5			700	690	535							
2.7	13.6	.7	19	108	27	5	1.7	.72	650	555	375	3.71	.27	8.2	9.6	.65	.37	.21
3.0	14.0	1.0	17	112	28	9			700	555	305	2.40	.30	11.0	9.7	.51	.28	.20
3.3	14.3	1.3	15	92	18	11	1.8	.54	650	470	290	2.60	.36	9.8	8.0	.47	.34	.15
3.7	14.7	1.6	15	92	19	12			650	445	230	2.60	.30	7.2	7.0	.39	.31	.14
4.0	15.0	2.0	26	92	13	13	1.8	.62	550	425	275	2.35	.21	7.8	6.6	.43	.37	.20
4.3	15.3	.3	38	116	13	14			650	505	395	2.21	.24	9.7	7.6	.56	.35	.20
4.6	15.6	.7	27	128	18	17	1.8	1.28	600	660	475	2.26	.34	13.3	12.0	.83	.35	.35
5.1	16.1	1.2	22	144	20	20			550	675	510	2.53	.38	12.3	10.0	.65	.41	.27
5.6	16.6	1.7	30	144	2	23	2.5	.56	750	605	395	2.37	.25	9.3	7.4	.62	.33	.23
6.1	17.1	2.2	83	236	48	27			750	1205	920	1.88	.30	17.9	10.6	1.18	.74	.37
6.6	17.6	.5	61	268	44	41	3.0	1.29	850	1540	1135	1.91	.29	21.7	13.4	1.14	.67	.53
7.1	18.1	1.0	26	288	44	51			950	1080	870	2.16	.25	15.3	13.2	.73	.56	.41
7.6	18.6	1.5	13	152	29	15	1.9	.59	650	720	485	2.08	.30	13.1	9.2	.64	.41	.27
8.1	19.1	2.0	9	120	17	11			600	595	430	2.51	.26	9.8	10.0	.58	.38	.24
8.6	19.6	2.5	7	84	17	13	1.4	.47	650	460	250	3.13	.28	6.8	6.3	.43	.21	.14
9.1	20.1	3.0	5	80	18	25			550	385	195	3.36	.27	7.1	8.0	.42	.23	.16

Table 33. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 7
Date: 2/1/72

Time (hrs) From			Q	Organics mg/1			Fecal Coliforms	Nutrients mg/1		Solids mg/1		Metals mg/1							
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD	#/ml	K-N	Total P	Total	SS	Ca	Cr	Fe	Mg	Mn	Pb	Zn	Ph
.5	285	285	3	322	115		145	2.2	4.1	985	660	6.8	.47	20.0	10.8	1.68	1.14	.70	7.3
1.0	285	285	28	473	143	20	135					3.8	.36	19.6	16.4	1.54	.68	.84	7.0
1.5	286	286	96	442	140		325	1.0	1.55	2725	2640	1.9	.45	25.6	20.8	1.48	1.12	.88	7.1
2.5	287	1.0	102	186	46	2	60					1.5	.41	15.8	10.6	.79	.61	.42	7.1
3.0	287	1.5	84	153	16		90	.4	.67	1375	1295	2.1	.13	12.4	6.8	.64	.71	.30	7.1
3.5	288	2.0	75	125	12		60					2.0	.23	9.7	6.9	.48	.32	.24	7.1
4.0	288	2.5	81	184	38		65	.3	.53	1285	1180	1.8	.33	9.7	6.0	.45	.36	.24	7.1
4.5	289	3.0	90	125	12	3	15					1.8	.32	10.0	6.7	.53	.53	.30	7.1
5.0	289	3.5	110	145	41		70	.3	.57	1500	770	1.6	.34	10.8	7.5	.61	.47	.26	7.1
5.5	290	4.0	113	161	28		130					1.5	.21	10.1	7.5	.66	.46	.31	7.1
6.0	290	.5	136	125	16		135	.5	.63	1910	1810	1.9	.35	9.1	6.6	.59	.43	.26	7.0
6.5	291	.3	112	148	31		75					1.9	.21	11.4	7.2	.57	.31	.34	7.0
7.0	291	.8	111	182	28		175	.2	1.21	1330	1335	1.8	.36	11.2	9.6	.68	.27	.32	7.0
7.5	292	1.3	138	163	13	7	65					1.8	.26	11.4	9.6	.66	.57	.35	7.1
8.0	292	.5	118	156	24		140	.3	.95	1545	1405	1.9	.34	11.3	9.7	.68	.37	.30	7.0
8.5	293	1.0	95	272	10	5	165					1.8	.21	11.4	7.3	.51	.47	.32	7.1
9.0	293	1.5	76	97	9		115	.3	.53	2265	1625	2.4	.08	7.3	6.1	.36	.28	.19	7.2
9.5	294	2.0	49	225	28	8	105					2.8	.25	8.4	8.0	.45	.26	.29	7.1
10.0	294	2.5	32	144	16		115	.8	.57	1850	1665	3.1	.31	8.1	8.4	.45	.27	.24	7.2
10.5	295	3.0	22	272	8	5	45					4.7	.29	6.4	8.3	.46	.34	.17	7.2
11.0	295	3.5	15	99	8		5	1.1	.5	1660	1640	5.0	.28	6.6	8.1	.48	.21	.20	7.2
11.5	296	4.0	11	91	7	6						6.0	.23	5.2	11.7	.46	.16	.22	7.4

Table 34. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 8
Date: 2/12/72

Time (hrs) From			Q CFS	Organics mg/l		Fecal Coliforms	Nutrients mg/l		Solids mg/l		Metals mg/l							pH
Storm Start	Last Storm	Last Peak		COD	TOC	#/ml	K-N	Total P	Total	SS	Ca	Cr	Fe	Mg	Mn	Pb	Zn	
4.5	220	220	3		39	168												
5.0	220.5	220.5	23	283	45	137			2160	1880	3.6	.24	28.8	16.4	1.45	.74	.76	7.5
5.5	221	221	34	198	41	75	.6	.48	1420	1040	2.7	.11	12.9	12.4	.65	.70	.41	7.0
6.0	221.5	221.5	38	141	32	58			1500	1390	2.8	.09	11.4	10.4	.50	.60	.36	7.2
6.25	221.7	.0	36	98		92			670	510	2.6	.25	9.8	9.2	.41	.46	.24	7.0
6.5	222	1.0	33	169	40	80	.5	.59	2500	2120	1.7	.26	13.4	9.8	.62	.51	.29	7.3
7.0	222.5	1.5	31	133	26	53			2020	1780	2.1	.23	9.9	9.[illegible]	.54	.32	.29	7.0
7.5	223	2.0	23	118	25	55	.2	.37	1520	1430	2.2	.27	8.8	6.1	.45	.29	.18	7.1
8.0	223.5	2.5	18	94	26	70			1420	1020	2.5	.30	6.6	5.6	.30	.40	.17	7.2
8.5	224	3	27	112	19	55	.2	.44	2460	2750	2.7	.34	7.4	7.1	.43	.36	.21	7.1
9.0	224.5	3.5	76	22[illegible]	55	48			2210	2060	2.1	.24	12.6	6.8	.62	.52	.31	7.1
9.5	225	.3	76	255	51	109	.5	.93	2570	2620	1.9	.25	17.6	11.4	.84	.63	.49	7.1
10.0	225.5	.8	63	149	39	115			2140	2000	1.9	.35	12.8	11.0	.64	.50	.35	7.2
10.5	226	1.3	39	423	67	58	1.0	.98			4.0	.23	12.3	14.6	.64	.37	.35	7.3
17.0	232.5	7.5	17	47	18	87			340	115	3.6	.30	4.6	6.1	.33	.27	.13	6.9
17.5	233	8.0	16	43	20	69	.4	.33	290	115	5.1	.32	2.7	6.0	.26	.24	.15	6.9
18.0	233.5	8.5	13	43	20	48			305	110	4.6	.30	4.0	6.5	.25	.24	.10	6.8

Table 35. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 9

Date: 2/18/72

Time (hrs) From			Q CFS	Organics mg/1		Fecal Coliforms	Nutrients mg/1		Solids mg/1		Metals mg/1						pH
Storm Start	Last Storm	Last Peak		COD	TOC	#/ml	K-N	Total P	SS	VSS	Ca	Fe	Mg	Mn	Pb	Zn	
.1	135	135	3	454	70	184	.7	1.70	3730	340	3.8	24.6	14.8	1.04	1.09	4.58	7.0
.5	136	135	24	282		197					3.0	13.5	11.1	.75	.86	.97	
1.0	136	.5	26	165	30	77	.3	.60	1620	95	2.1	13.1	10.7	.63	.74	.96	6.9
1.5	137	1.0	29	161		61					2.0	15.1	9.0	.55	.47	.66	
2.0	137	.5	20	133	24	56	.7	.44	1050	50	2.3	12.4	9.2	.62	.55	.55	7.2
2.5	138	1.0	16	94		91					2.6	8.8	8.7	.43	<.1	.44	
3	138	1.5	12	90	10	71	.3	.36	1340	25	2.2	9.0	7.9	.47	.35	.44	7.3
3.5	139	2.0	7	82		39					3.1	8.4	7.6	.43	.24	.37	
4	139	2.5	6	79	16	31	.9	.32	3000	20	3.3	7.5	7.2	.57	.29	.39	7.3
4.5	140	3.0	6	79		24					4.6	6.7	8.7	.71	.30	.39	
5	140	3.5	7	115	22	80	1.7	.47	850	80	6.0	10.3	8.8	.59	.32	.47	7.4
6	141	4.5	22	226		30					4.8	6.4	6.5	.49	.36	.43	
6.5	142	5.0	24	83	21	35	.2	.29	490	25	4.7	8.6	6.5	.37	.29	.53	7.1
7	142	.5	23	123		30					4.8	6.7	6.2	.52	<.1	.52	
7.5	143	1.0	23	87	19	33	.4	.33	530	30	5.3	7.0	7.1	.47	.36	.44	7.3
8	143	1.5	21	459		36					4.9	8.9	7.4	.48	.40	.53	
8.5	144	2.0	20	87	20	26	.6	.25	970	35	4.8	5.6	6.4	.39	.10	.41	7.3
9.5	145	3.0	16	79		26					4.3	5.8	6.7	.42	.25	.33	
10	145	3.5	14	63	13	10	.6	.30	2090	50	4.8	4.2	5.9	.28	<.1	.27	7.4
11	146	4.5	10	67		6					5.1	4.0	5.6	.38	<.1	.30	
11.5	147	5.0	9	123		115			3620	75	6.6	5.0	9.3	.47	.15	.31	7.8

Table 36. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 10

Date: 2/23/72

Time (hrs) From			Q CFS	Organics mg/1		Fecal Coliforms	Nutrients mg/1		Solids mg/1		Metals mg/1						pH
Storm Start	Last Storm	Last Peak		COD	TOC	#/ml	K-N	Total P	Total	SS	Ca	Fe	Mg	Mn	Pb	Zn	
.1	111	111	1	47	8	36	.4	.53	455	70	31.2	2.8	14	.67	.29	.33	7.7
1	112	112	1	63	22	53	.7	.44	765	215	28.4	5.8	15.2	.75	.22	.38	7.6
2	113	113	16	286	75	108	.7	1.03	1435	725	3.5	13.1	10	.77	.96	1.08	7.2
3	114	1	7	137	52	80	.6	.46	1035	755	3.8	9.6	7.8	.62	.59	.62	7.3
4	115	2	4	90	24	57	.6	.4	1220	1095	4.7	7.6	9.2	.42	.32	.52	7.4

Table 37. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 11

Date: 2/26/72

Time (hrs) From			Q CFS	Organics mg/l		Nutrients mg/l		Solids mg/l		Metals mg/l						pH
Storm Start	Last Storm	Last Peak		COD	TOC	K-N	Total P	Total	SS	Ca	Fe	Mg	Mn	Pb	Zn	
.5	68	68	18	714		.7	1.95		3505	2.5	34.7	24	2.11	2.86	3.36	7.2
1	68.5	68.5	20	407	104			2310	2295							
1.5	69	.5	13	326		.5	1.40		2030	3.0	31.4	16.4	1.27	1.06	1.83	7.2
2	69.5	1	7	241	46			1455	1350							
2.5	70	1.5	4	167		.5	1		895	3.2	19	12	.89	.42	.91	7.2
3	70.5	2	3	159	45			1275	1050							
3.5	71	2.5	3	140		.4	.7		725	4.1	11.5	12.9	.75	.47	.71	7.2
4	71.5	3	2	140	35			1105	895							
4.5	72	3.5	2	123		.5	.77		590	4.5	10.6	11.3	.67	.21	.63	7.3
5	72.5	4	2	77	19			585	360							
5.5	73	4.5	2	108		.8	.76		475	5.6	8.4	11.4	.7	<.1	.51	7.4
6	73.5	5	2	88	35			1245	700							
6.5	74	5.5	2	115		.9	.77		710	6.9	9.1	12.4	.68	.19	.58	7.5
7	74.5	6	1	104	29			1115	800							
7.5	75	6.5	1	104		.6	1.15		760	7.7	9.8	14.8	.63	.3	.53	7.5
8	75.5	7	1	115	16			950	750							
8.5	76	7.5	1	111		1.1	1.1		575	7.8	7.9	14.7	.66	.36	.49	7.6
9	76.5	8	1	104	24			825	575							
9.5	77	8.5	1	127		1.3	.95		785	8.0	8.7	18.1	.78	.22	.54	7.6
10	77.5	9	1	104	28			1190	775							
10.5	78	9.5	1	115		1.1	1.1		795	14.8	8.2	19.5	.7	.17	.53	7.5
11	78.5	10	1	71	17			800	390							

Table 38. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 12
Date: 3/8/72

Time (hrs) From			Q	Organics mg/1			Fecal Coliforms	Nutrients mg/1		Solids mg/1				Metals mg/1						pH
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD	#/ml	K-N	Total P	TS	VS	TSS	VSS	Ca	Fe	Mg	Mn	Pb	Zn	
.5	278	278	3	163	47		253					205	30							
.8	278.3	278.3	4	136		35	151	.8	1.2	480	90	205	25	17.6	5.4	10.4	.51	.25	.31	7.4
1.2	278.7	.3	4	120	44		136					200	15							
1.5	279	.7	4	116		23	128	.6	1.0	455	85	200	25	28.9	4.4	7	.36	.1	.25	7.3
1.8	279.3	1	4	97	32		116					140	10							
2.2	279.7	1.3	3	93		17	109	.9	.85	405	105	145	20	23.7	4.2	7.2	.41	.35	.3	7.2
2.5	280	1.7	3	74	39		147					85	10							
2.8	280.3	2	2	66		12	117	.6	.55	330	70	80	15	19.4	3.2	9.8	.48	.39	.21	7.4
3.2	280.7	2.3	2	47	36		73					55								
3.5	281	2.6	2	66		11	70	.7	.6	305	52	135	10	24.6	2.9	11	.51	.35	.17	7.2
3.8	281.3	3	1	43	32		42					120	5							
4.2	281.7	3.3	1	43		7	35	.5	.75	370	82	95	5	30.5	2.9	10.6	.47	.32	.17	7.5
4.8	282.3	4	1	47	17		31					135								
5.2	282.7	4.3	1	43		2	17	.5	.75	390	60	250	10	28.3	3	10	.39	<.1	.13	7.5

Table 39. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 13
Date: 3/16/72

Time (hrs) From			Q	Organics mg/1			Nutrients mg/1		Fecal Coliforms	Solids mg/1				Metals mg/1						pH
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD	K-N	Total P	#/ml	Total	VS	SS	VSS	Ca	Fe	Mg	Mn	Pb	Zn	
1.0	200	200	3	353		40			125			680	160							
1.3	200	200	20	596	18		1.1	1.6	197	1840	380	1670	280	6.1	33.9	12.4	1.20	.73	1.03	7.0
1.7	201	201	38	404		32			174			920	250							
2.0	201	201	44	306	97		.2	1.0	349	1070	300	990	180	3.9	20.9	8.4	.69	.74	.62	6.9
2.3	201	.3	38	194		30			79			650	130							
2.7	202	.7	29	145	42		.6	.60	159	700	180	640	120	4.0	15.1	7.4	.55	.33	.25	6.9
3.0	202	1.0	17	124		20			152			530	110							
3.3	202	1.3	13	98	28		.7	.70	133	560	150	530	80	4.2	10.5	6.4	.46	.39	.28	7.0
3.7	203	1.7	8	82		7			112			280	90							
4.0	203	2.0	6	67	26		.6	.35	116	360	140	310	60	5.3	6.7	6.3	.30	.35	.15	7.2
4.3	203	2.3	4	66		6			98			290	70							
4.7	204	2.7	3	59	26		.6	.35	107	410	120	360	60	5.8	6.2	5.2	.28	.10	.10	7.2
5.0	204	3.0	2	78		13			91			350	60							
5.3	204	3.3	2	64	35		.6	.40	59	990	190	890	80	6.5	7.4	8.0	.32	.13	.22	7.3
5.7	205	3.7	2	62		5			54			280	80							
6.0	205	4.0	2	59	23		.6	.37	66	650	180	490	70	7.4	6.3	9.6	.33	<.1	.12	7.3
6.3	205	4.3	2	101		8			93			330	80							
6.7	206	4.7	2	93	37		.7	.41	131	710	210	490	70	6.4	7.3	5.0	.41	.25	.30	7.2
7.0	206	5.0	3	105		16			163			370	70							
7.3	206	5.3	3	97	49		.6	.39	94	620	180	490	60	5.3	7.4	4.8	.27	.17	.25	7.1
7.7	207	5.7	4	98		23			95			890	140							
8.0	207	6.0	14	380	109		.4	1.30	272	2130	330	2160	250	3.4	27.5	18.0	.85	.94	.68	7.0
8.3	207	6.3	41	283		32			225			1220	180							

Table 40. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 14

Date: 3/31/72

Time (hrs) From			Q CFS	Organics mg/1		Solids mg/1				Metals mg/1						pH
Storm Start	Last Storm	Last Peak		COD	TOC	Total	VS	SS	VSS	Ca	Fe	Mg	Mn	Pb	Zn	
.5	240	240	3	334	38			1100	165	7.8	11.7	13.4	.93	.38	.37	
1.0	240	240	11	202		1010	185	910	150							7.4
1.5	241	241	21	171	65			1010	125	3.6	11.1	6.8	.45	.44	.27	
2.0	241	.3	21	124		1145	165	1030	105							7.1
2.5	242	.8	16	299	82			2095	165	3.3	5.4	11.2	.77	.46	.42	
3.0	242	1.3	9	78		750	145	655	65							7.2
3.5	243	1.8	7	66	28			610	55	3.8	6.3	5.4	.27	.16	.31	
4.0	243	2.3	7	50		715	85	575	45							7.2
4.5	244	2.8	7	58	32			485	55	4.4	5.7	6.0	.39	.20	.14	
5.0	244	3.3	7	58		475	65	325	40							7.2
5.5	245	3.8	7	62	24			545	60	4.4	4.3	5.6	.17	.13	.13	
6.0	245	4.3	9	101		800	150	700	65							7.1
6.5	246	4.8	41	182	81			1325	115	2.6	15.8	9.8	.63	.48	.40	
7.0	246	.5	30	147		1785	175	1730	110							7.1
7.5	247	1.0	17	93	49			1045	85	2.8	12.9	8.2	.42	.30	.26	
8.0	247	1.5	10	109		1325	190	895	75							7.0
8.5	248	2.0	6	106	42			2020	95	3.4	8.9	8.8	.34	<.1	.27	
9.0	248	2.5	5	125		1765	165	1705	130							7.3
9.5	249	3.0	4	106	29			1450	85	4.4	10.0	8.6	.27	.20	.18	
10.0	249	3.5	4	82		1520	140	1260	85							7.3
10.5	250	4.5	4	102	40			1435	95	4.6	8.6	10.4	.35	.21	.23	
11.0	250	4.5	4	78		1080	150	770	70							7.3
11.5	251	5.0	5	98	35			1365	80	4.9	11.5	9.6	.28	.48	.23	

Table 41. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 15
Date: 4/12/72

Time (hrs) From			Q CFS	Organics mg/1			Solids mg/1				Metals mg/1						pH	ALK mg/1 as $CaCO_3$
Storm Start	Last Storm	Last Peak		COD	TOC	BOD	Total	Vs	SS	VSS	Ca	Fe	Hg	Mn	Pb	Zn		
.8	104	104	28	161		28			775	140	3.9	9.5	8.2	.49	.40	.28	7.1	
1.3	105	.5	38	141	56		1195	120	1030	160								34
1.8	105	1.0	73	138		24			1555	205	2.2	13.9	9.4	.65	.51	.41	7.1	
2.3	106	.5	50	133	44	16	1620	200	1650	180								
2.8	106	1.0	18	114					1060	145	2.4	7.0	6.6	.40	.11	.27	7.1	
3.3	107	1.5	9	82	30	13	945	150	805	130								26
3.8	107	2.0	5	63					505	110	3.5	11.8	6.6	.21	.15	.17	7.3	
4.3	108	2.5	4	63	28	10	565	150	420	105								
4.8	108	3.0	3	51					350	70	4.7	4.9	6.6	.21	.18	.14	7.4	
5.3	109	3.5	3	39	24	12	510	145	345	95								47
6.3	110	4.5	2	55					395	90	7.0	1.3	8.4	.20	.17	.10	7.4	
6.8	110	5.0	2	39	26	11	925	120	700	80								
7.3	111	5.5	2	47					1055	85	12.8	5.3	8.4	.20	<.1	.11	7.5	60
7.8	111	6.0	2	71		34			1115	100								

Table 42. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 16
Date: 5/3/72

Time (hrs) From			Q CFS	Organics mg/1		Nutrients mg/1		Fecal Coliforms	Solids mg/1				Metals mg/1				pH	ALK mg/1 as
Storm Start	Last Storm	Last Peak		COD	TOC	K-N	Total P	#/ml	Total	VS	SS	VSS	Cr	Cu	Pb	Zn		$CaCo_3$
.1	504	504	1	492	37			63	4220	320	3400	170	.12	<.1	.40	.78	7.3	138
.5	505	505	19	641	37	1.3	1.2	66			7340	320	.18	.17	.97	1.05		
1.0	505	505	43	157	26			72	840	140	640	90	.11	<.1	.13	.27	7.2	
1.5	506	506	72	626	34	2.1	2.4	240			4040	300	.41	.27	.91	1.28		
2.0	506	.5	63	238	12			160	1290	180	1290	140	.15	.10	.55	.57	6.8	
2.5	507	1.0	50	227	11	0.7	1.2	150			2310	200	.17	.20	.85	.77		
3.0	507	1.5	43	165	11			160	1290	160	1230	130	.10	.10	.13	.47	7.0	24
3.5	508	2.0	27	146	8	0.1	.6	130			1700	130	.10	.10	.31	.34		
4.0	508	2.5	24	141	12			130	1510	120	1780	80	.10	<.1	.27	.29	7.1	
4.5	509	3.0	21	114	13	0.4	.4	120			890	40	.10	.10	.20	.27		
5.0	509	3.5	18	118	11			150	840	130	660	40	<.1	<.1	.19	.21	7.2	
5.5	510	4.0	16	91	20	0.4	.4	130			670	60	<.1	<.1	.16	.18		
6.0	510	4.5	41	152	15			110	1280	150	1360	50	<.1	.13	.24	.28	7.2	32
6.5	511	5.0	136	597	8	0.5	2.4	160			7310	420	.33	.29	2.06	1.47		
7.5	512	1.0	119	262	10			180	2230	250	2430	220	.25	<.1	.46	.65	6.7	
8.0	512	1.5	98	182	10	0.4	1.0	200			2330	100	.12	<.1	.34	.40		
8.5	513	2.0	74	175	12			190	3910	190	3700	130	.10	.12	.34	.33	7.0	
9.0	513	2.5	43	103	22	0.4	.4	130			5330	110	<.1	<.1	.10	.17		28
9.5	514	3.0	16	475	11			170					.12	<.1	.35	.32	7.2	
10.5	515	4.0	14	346	8	0.5	.3	140					<.1	<.1	<.1	.10		
11.0	515	4.5	13	825	16			150					<.1	<.1	.12	.33	7.2	

Table 43. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 17
Date: 5/14/72

Time (hrs) From			Q	Organics mg/1			Nutrients mg/1		Fecal Coliforms	Solids mg/1				Metals mg/1				pH	ALK mg/1 as
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD	K-N	Total P	#/ml	Total	VS	SS	VSS	Cr	Cu	Pb	Zn		$CaCO_3$
.1	254	254	1	939	31				96					.20	.11	.89	.89	7.4	132
.5	255	255	2	120	18		.7	1.0	140	1360	135	930	40	<.1	<.1	.21	.26	7.3	
1.0	255	255	2	124	28	71			86			915	45	.10	<.1	<.1	.16	7.2	
1.5	256	256	2	128	34		.9	.44	72	1455	130	1260	15	<.1	.11	<.1	.15	7.1	76
2.0	256	256	2	120	25	53			140			465	35	.11	<.1	.18	.15	7.0	
2.5	257	257	33	198	26		.6	1.0	150	1360	150	1440	95	.25	.12	.40	.44	6.9	
3.0	257	257	41	124	12	39			100			1260	40	.16	<.1	.22	.27	6.8	26
3.5	258	0.5	20	70	12		.4	.35	94	835	90	805	90	.12	<.1	.13	.21	6.8	
4.0	258	1.0	36	82	11	37			93			775	85	<.1	<.1	.17	.19	6.9	
4.5	259	1.5	105	136	9		.4	.50	210	1395	145	1325	185	<.11	.10	.32	.34	7.0	18
5.0	259	.5	63	147	7	40			210			1245	85	.10	.13	.34	.34	7.0	
5.5	260	1.0	23	116	9		.3	.60	190	1160	165	1070	125	.11	<.1	.14	.24	6.8	
6.0	260	1.5	11	109	8	34			180			1915	120	<.1	<.1	<.1	.21	6.9	14
6.5	261	2.0	47	85	12		.4	.45	190	2415	140	2730	65	<.1	<.1	.19	.21	7.0	
7.0	261	2.5	63	85	9	39			180			1385	110	<.1	<.1	<.1	.15	7.2	
7.5	262	0.5	22	182	6		.3	.60	170	2230	235	2275	190	.12	<.1	.40	.23	7.1	20
8.0	262	1.0	10	144	7	39			200			1825	125	.12	<.1	.29	.37	6.9	
8.5	263	1.5	7	85	9		.3	.55	220	2175	95	2255	140	<.1	<.1	.25	.22	7.1	
9.0	263	2.0	6	81	12	36			260			2470	95	<.1	<.1	.10	.19	7.1	28
9.5	264	2.5	6	89	14		.3	.35	200	1830	90	1795	65	<.1	.10	.38	.16	7.2	
10.0	264	3.0	6	89	14	36			180			2665	60	<.1	<.1	.11	.15	7.3	
10.5	265	3.5	5	66	14		.3	.35	150	1195	85	1220	60	<.1	<.1	<.1	.11	7.6	46
11.0	265	4.0	4		14				190					<.1	<.1	.13	.19	7.6	

Table 44. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 18
Date: 5/22/72

Time (hrs) From			Q CFS	Organics mg/l		Nutrients mg/l		Fecal Coliforms	Solids mg/l				Metals mg/l				pH	ALK mg/l as
Storm Start	Last Storm	Last Peak		COD	TOC	K-N	Total P	#/ml	Total	VS	SS	VSS	Cr	Cu	Pb	Zn		$CaCO_3$
2.3	130	2.0	10	51	24	.3	.20	4	3350	135	3770	85	<.1	<.1	<.1	.12	7.8	122
2.8	130	2.5	124	35	23	.3	1.10	4			295	65						
3.3	131	3.0	345	31	12	.3		2	580	100	245	80	<.1	<.1	<.1	.10	7.8	
3.8	131	0.5	187	35	12	.3	.34	2			360	75						
4.3	132	1.0	117	39	16	.3	.35	5	820	100	560	85	<.1	<.1	<.1	.09	7.8	114
4.8	132	1.5	58	50	13	.4	.79	6			755	85						
5.3	133	2.0	25	43	17	.3	.72	4	680	110	395	80	<.1	<.1	<.1	.10	7.7	
5.8	133	2.5	17	47	14	.3	.60	4			900	85						
6.3	134	3.0	10	39	10	.3	.44	1	645	90	365	40	<.1	<.1	<.1	.09	7.7	122

Table 45. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 19
Date: 5/31/72

Time (hrs) From			Q CFS	Organics mg/l			Nutrients mg/l		Fecal Coliforms	Solids mg/l				Metals mg/l					pH	ALK mg/l
Storm Start	Last Storm	Last Peak		COD	TOC	BOD_5	K-N	Total P	#/ml	Total	VS	SS	VSS	Co	Fe	Mn	Ni	Pb		$CaCO_3$
.5	141	141	30	367	92	9	.7	1.1	1100			2095	245							
1.0	141	.5	15	232	65				1000	1455	180	1245	130	<.1	23.3	1.63	<.1	1.27	7.2	40
1.5	142	1.0	12	142	40	4	1.0	.67	400			820	75							
2.0	142	1.5	4	106	36				350	1090	110	895	70	<.1	9.8	.49	<.1	.40	7.2	50
2.5	143	2.0	2	92	32	3	.8	.39	200			575	35							
3.0	143	2.5	2	96	26				170	995	90	910	45	<.1	14.7	.33	<.1	.14	7.4	56
3.5	144	3.0	1	56	14	3	.8	.36	160			275	30							
4.0	144	3.5	1	62	27				160	425	60	375	25	<.1	3.7	1.83	<.1	<.1	7.5	62

Table 46. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 20
Date: 6/20/72

Time (hrs) From			Q	Organics mg/1			Nutrients mg/1		Fecal Coliforms	Solids mg/1				Metals mg/1					pH	ALK mg/1
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD	K-N	Total P	#/ml	Total	VS	SS	VSS	Co	Fe	Mn	Ni	Pb		$CaCO_3$
.1	494	494	1	359	50	>74	1.4	1.60	2000			530	95	<.1	12.9	1.76	<.1	.56		
.5	495	495	1	294	51	>77	1.4	.88	810	585	160			<.1	4.2	1.04	<.1	.36	7.5	98
1.0	495	495	1	171	70	55	1.0	.47	440			115	65	<.1	2.6	.61	<.1	.35		
1.5	496	496	1	127	38	51	.9	.42	370	390	105			<.1	1.6	.52	<.1	.37		
2.0	496	496	1	196	63	59	1.0	.53	120			175	70	<.1	2.4	.59	<.1	.17	7.1	
2.5	497	497	4	353	26	74	1.1	3.0	1100	1130	220			<.1	18.3	2.31	<.1	.72		
3.0	497	497	75	605	33	76	1.2	3.5	740			2620	375	<.1	27.0	2.25	<.1	1.51	7.1	42
3.5	498	0.5	19	247	37	50	.8	1.2	510	1070	165			<.1	25.0	1.07	<.1	1.16		
4.0	498	1.0	11	135	29	50	.8	.86	20			705	125	<.1	16.3	.84	<.1	.46		
4.5	499	1.5	5	147	26	48	.6	1.1	520	735	110			<.1	20.1	.64	<.1	.58	7.2	
5.5	500	2.5	3	116	72	40	.5	.57	5			1060	95	<.1	5.9	.44	<.1	.18		
6.0	500	3.0	3	137	21	45	.7	.69	320	1310	125			<.1	15.1	.58	<.1	.51	7.3	45
6.5	501	3.5	4	149	21	42	.7	.59	20			1135	110	<.1	6.5	.66	<.1	.26		
7.0	501	4.0	3	120	27	39	.5	.54	5	875	130			<.1	12.4	.54	<.1	<.1	7.1	
7.5	502	4.5	2	144	25	42	.7	.50	30			820	100	<.1	11.6	.53	<.1	.16		

Table 47. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 21
Date: 6/28/72

Time (hrs) From			Q	Organics mg/1			Nutrients mg/1				Fecal Coliforms	Solids mg/1				Metals mg/1			
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD_5	K-N	NH_4-N	$NO_2^-+NO_3^-$	Total P	#/ml	Total	VS	SS	VSS	Cd	Mg	Mn	Zn
0.1	172	172	9	443		146	.9	.44	<.05	2.1	300	2790	350	2710	280	<.1	14.4	2.28	1.06
.5	172	172	365	374	108	102	.6	.05	.52	1.2	340			3960	305				
1.3	173	173	1740	212		96	.4	.12	.52	1.0	320	2130	225	2085	265	<.1	12.4	1.74	.62
1.5	173	.3	1230	174	52	92	.3	.10	.32	.86	450			2350	215				
2.0	174	.8	563	150	60	90	.3	.12	.68	.69	400			2555	135				

Table 48. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 22
Date: 7/11/72

Time (hrs) From			Q	Organics mg/1			Nutrients mg/1		Fecal Coliforms	Solids mg/1				Metals mg/1				pH	ALK mg/1
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD	K-N	Total P	#/ml	Total	VS	SS	VSS	Cd	Mg	Mn	Zn		$CaCO_3$
.5	157	157	2	144	92	64	.4	.86	80	1430	220	930	150	<.1	12.9	.74	.48	8.1	124
1.0	158	158	2	161	62	66	.4	1.1	110	2720	240	2010	160	<.1	12.3	.64	.44	7.9	126
1.5	158	158	2	1043	384	84	1.1	1.7	270	7940	1170	3230	970	<.1	13.5	.94	.47	7.6	94
2.0	159	.5	1	260	122	78	.7	.86	240	3670	370	3160	240	<.1	10.8	.53	.33	7.7	102

Table 49. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 23
Date: 7/12/72

Time (hrs) From			Q	Organics mg/1			Nutrients mg/1		Fecal Coliforms	Solids mg/1				Metals mg/1				pH	ALK mg/1
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD	K-N	Total P	#/ml	Total	VS	SS	VSS	Cd	Mg	Mn	Zn		$CaCO_3$
1.3	176	176	29	219	110	110	.5	1.0	660			855	115	<.1	5.4	.95	.43	7.7	40
1.8	177	.5	25	175	42		.3	.66	290	720	190	625	65	<.1					
2.3	177	1.0	36	134	43	96	.2	.66	320			695	40	<.1	4.8	.56	.26	7.3	
2.8	178	.5	23	101	48		.2	.39	280	655	190	535	35	<.1					
3.3	178	1.0	15	74	25	100	.2	.34	280			405	30	<.1	4.2	.31	.14	7.5	26
3.8	179	1.5	9	64	40		.2	.31	310	360	135	215	0	<.1					
4.3	179	2.0	7	65	27	100	.2	.34	250			420	20	<.1	3.9	.28	.17	7.4	
4.8	180	2.5	8	105	56		.3	.42	260	965	170	875	35	<.1					
5.3	180	3.0	8	113	25	96	.3	.52	120			540	35	<.1	5.1	.41	.29	7.1	36
5.8	181	3.5	4	84	26		.3	.36	240	715	180	540	15	<.1					
6.3	181	4.0	3	111	26	98	.2	.43	290			860	45	<.1	6.0	.36	.22	7.5	
6.8	182	4.5	2	76	32		.2	.32	350	1140	190	940	20	<.1					
7.3	182	5.0	2	80	35	100	.3	.42	240			720	20	<.1	4.8	.29	.15	7.6	40
7.8	183	5.5	1	20	18		.2	.28	200	220	120	45	0	<.1					
8.3	183	6.0	1	21	14	104	.2	.24	110			35	0	<.1	3.6	.12	<.1	7.4	

Table 50. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 24
Date: 7/17/72

Time (hrs) From			Q CFS	Organics mg/1			Nutrients mg/1		Fecal Coliforms	Solids mg/1				Metals mg/1				pH	ALK mg/1
Storm Start	Last Storm	Last Peak		COD	TOC	BOD	K-N	Total P	#/ml	Total	VS	SS	VSS	Cd	Mg	Mn	Zn		$CaCO_3$
.3	126	126	112	143	113	104	.9	2.1	1300			385	65	<.1	9.9	1.70	.26	7.9	102
.5	126	.1	112	543	158		.4	1.8	330	4600	595	4445	465						
.8	127	.4	88	686	134	86	.3	1.3	680			3135	380	<.1	13.2	1.80	.68	7.2	
1.0	127	.1	125	364	80		.2	1.3	470	2885	395	2900	300						
1.3	127	.4	82	261	66	72	.2	1.1	190			3700	400	<.1	13.2	1.88	.64	7.0	23
1.5	127	.6	25	239	62		.2	1.2	420	3225	465	3150	345						
1.8	128	.8	17	202	48	60	.2	1.2	450			2510	270	<.1	11.4	1.32	.56	7.0	

Table 51. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 25
Date: 7/31/72

Time (hrs) From			Q	Organics mg/1			Nutrients mg/1		Solids mg/1				Metals mg/1					pH	ALK mg/1
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD	K-N	Total P	Total	VS	SS	VSS	Ca	Cr	Cu	Mg	Zn		$CaCO_3$
.3	15	15	55	412	76	16	.3	.92	6040	400	6720	220	3.0	.22	<.1	11.4	.61	7.5	50
.5	15	15	137	348	78	18	.2	1.50	3454	450	6270	370	2.2	.19	.18	10.8	.32		
.8	16	16	94	230	56	20	.2	.86	2830	340	3230	90	1.8	.21	<.1	8.8	.50	7.3	
1.0	16	.3	47	202	37	18	.2	.83	2570	260	2920	110	1.6	<.1	.14	6.8	.40		
1.3	16	.5	45	202	34	14	.2	.66	2820	310	3100	130	1.8	.23	<.1	7.6	.43	7.6	24
1.5	16	.8	87	198	40	18	.2	.89	3540	330	3980	220	1.6	.18	.13	11.0	.47		
1.8	17	1.0	139	242	64	14	.3	.72	3510	270	3240	160	1.5	.14	<.1	7.0	.46	7.4	
2.0	17	1.3	154	222	59	18	.3	.96	3600	350	3620	180	1.1	.22	.12	10.2	.40		
2.3	17	.3	70	198	52	12	.3	.78	3020	360	3100	0	1.4	.14	<.1	7.2	.33	7.3	26
2.5	17	.5	59	176	42	14	.3	.86	2850	270	2970	220	1.6	.16	<.1	8.2	.43		
2.8	18	.8	39	122	35	18	.4	.54	1560	230	1740	160	2.2	.15	<.1	6.4	.32	7.4	
3.0	18	1.0	25	161	37	16	.4	.65	2390	110	2430	130	2.0	.10	<.1	6.8	.29		
3.3	18	1.3	20	157	33	16	.4	.66	2960	110	3930	130	2.4	<.1	<.1	6.9	.28	7.6	32
3.5	18	1.5	18	165	54	14	.5	.58	4150	120	4810	130	2.5	<.1	<.1	5.2	.26		
3.8	19	1.8	16	118	44	14	.5	.56	2790	90	2760	30	2.8	<.1	<.1	5.0	.25	7.6	
4.0	19	2.0	16	137	40	18	.4	.56	2260	100	2600	50	3.1	.15	<.1	5.4	.24		
4.3	19	2.3	15	137	44	18	.5	.61	2710	110	2750	100	3.2	.10	<.1	5.4	.31	7.7	40
4.5	19	2.5	15	98	31	14	.5	.41	1910	80	1670	10	3.5	<.1	<.1	3.6	.18		
4.8	20	2.8	15	118	63	16	.5	.61	2960	110	2920	40	3.7	.13	<.1	5.4	.28	7.7	
5.8	21	3.8	14	102	45	12	.5	.51	1680	90	2080	90	4.1	<.1	<.1	5.8	.21		

Table 52. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 26

Date: 8/28/72

Time (hrs) From Storm Start	Last Storm	Last Peak	Q CFS	Organics mg/1 COD	Soluble COD	TOC	Solids mg/1 Total	VS	SS	VSS
.5	220	220	1	268	78	69	7300	460	5460	260
.8	220	220	4	175	78	50	6510	300	4890	140
1.0	221	.5	2	109	82	32	2460	210	1390	60

Table 53. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 27

Date: 9/17/72

Time (hrs) From			Q CFS	Organics mg/1			Nutrients mg/1		Fecal Coliforms	Solids mg/1				Metals mg/1				pH	ALK mg/1
Storm Start	Last Storm	Last Peak		COD	TOC	BOD_5	K-N	Total P	#/ml	Total	VS	SS	VSS	Fe	Mn	Pb	Sr		$CaCO_3$
.2	195	195	32	768	143	71	1.0	2.0	780	6960	710	6770	540	55.3	3.24	2.05	<.1	7.0	
1.7	196	196	154	357	76	37	.6	1.2	220	7460	350	6750	280	58.7	1.61	.88	<.1		
2.2	197	.5	115	172	50	30	.5	.87	160	2460	210	2170	120	24.2	1.07	.56	<.1	6.6	18
2.7	197	1.0	88	545	88	32	.4	1.1	100	8620	470		420	44.7	2.57	1.49	<.1		
3.0	198	1.3	365	129	32	29	.4	.68	100	1540	130	1440	100	31.6	.44	.37	<.1	6.8	
3.2	198	1.5	715	129	48	25	.4	.64	80	1430	130	1530	100	25.3	.92	.39	<.1		
3.4	198	.2	187	110	30	99	.4	.55	60	1010	230	940	170	25.4	1.33	.71	<.1	6.7	16
3.7	198	.5	154	125	14	30	.4	.52	80	1120	230	1000	190	19.6	.77	.42	<.1		
4.0	199	.8	133	78	17	30	.4	.46	20	1130	180	940	140	21.1	.63	.25	<.1	6.7	
4.2	199	1.0	115	114	12	28	.4	.45	120	1270	190	1160	150	22.7	.67	.18	<.1		

Table 54. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 28
Date: 9/21/72

Time (hrs) From			Q	Organics mg/1			Nutrients mg/1		Fecal Coliforms	Solids mg/1				Metals mg/1				pH	ALK mg/1
Storm Start	Last Storm	Last Peak	CFS	COD	Soluble COD	TOC	K-N	Total P	#/ml	Total	VS	SS	VSS	Fe	Mn	Pb	Sr		$CaCO_3$
.8	85	.1	39	279	92	20	.3	.52	400	1340	170	1180	90	16.3	.77	.44	<.1	7.2	28
1.0	85	.4	36	213	73	18	.3	.39	250	890	150	790	50	16.3	.61	.20	<.1		
1.3	86	.6	32	144	61	13			300	1050	170	970	80	23.8	.82	.20	<.1	7.4	
1.5	86	.8	24	124	61	18	.7		260	620	120	470	80	18.4	.54	.19	<.1		
1.8	86	1.1	21	105	65	12	.3	.32	230	1080	120	980	50	17.1	.43	.26	<.1	7.3	26
2.0	86	1.4	10	112	65	13	.3	.37	250	1110	130	890	40	6.2	.35	.33	<.1		
2.3	87	1.6	9	89	65	12	.3	.27	200	890	240	680	50	20.2	.40	.15	<.1	7.3	
2.5	87	1.8	8	101	61	31	.3	.35	180	1150	130	1080	60	21.8	.73	.23	<.1		
2.8	87	2.1	7	97	61	30	.3	.36	180	1510	120	1400	120	24.7	.66	.34	<.1	7.3	30
3.0	87	2.4	5	136	100	47	.2	.35	230	1830	120	1800	90	25.0	.73	.33	<.1		

Table 55. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 29
Date: 10/5/72

Time (hrs) From			Q	Organics mg/1			Nutrients mg/1		Solids mg/1				Metals mg/1					pH	ALK mg/1
Storm Start	Last Storm	Last Peak	CFS	COD	TOC	BOD_5	K-N	Total P	Total	VS	SS	VSS	Al	Ca	Cr	Cu	Mg		$CaCO_3$
.1	120	120	63	202	40	150	.4	.72	675	145	450	50	10.2	4.9	.12	.11	7.7	7.2	43
.4	120	120	325	229	68	150	.3	1.20	2680	295	2400	200	35.8	2.1	.18	.11	20.4		
.7	120	.1	169	109		120	.3	.64	1705	220	1590	120	27.8	1.7	.14	.15	15.3	6.8	
1.1	121	.4	455	155		130	.2	.61	1795	210	1595	115	26.4	2.0	.13	<.1	14.7		
1.4	121	.2	270	147		120	.2	.69	1480	175	1335	100	23.0	1.2	.23	<.1	11.2	7.0	14
1.7	121	.3	169	85		120	.2	.58	940	120	870	75	21.3	1.6	.14	.13	9.3		
2.2	122	.8	270	70		110	.2	.58	1135	140	1035	75	19.2	1.1	<.1	<.1	9.9	7.1	

Table 56. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 30
Date: 10/19/72

Time (hrs) From Storm Start	Last Storm	Last Peak	Q CFS	Organics mg/1 COD	TOC	BOD$_5$	Nutrients mg/1 K-N	Total P	Fecal Coliforms #/ml	Solids mg/1 SS	VSS	Metals mg/1 Al	Ca	Cr	Cu	Mg	pH	ALK mg/1 CaCO$_3$
Stage and				300	53	320	.5	1.3	160	870	170	10.3	35.8	.14	<.1	16.8	7.4	98
Precipitation				242	54	230	.6	.71	80	520	150	8.7	5.8	<.1	.16	11.0		
Recorders				188	46	210	.5	.66	40	610	140	9.6	4.1	.13	<.1	9.0	7.0	
Inoperable				207	73	210	.7	.76	100	800	190	14.9	3.6	.10	.10	10.0		
				157	38	150	.4	.92	100	4230	180	18.3	3.2	.13	.10	9.8	7.1	30
				119	27	170	.4	.54	120	640	150	10.2	3.4	.21	.10	9.4		
				104	42	160	.3	.50	80	640	140	12.4	3.4	<.1	<.1	10.0	7.1	
				108	32	150	.4	.57	100	390	120	10.0	3.8	<.1	<.1	10.6		
				111	38	150	.3	.56	120	1250	130	9.8	4.4	<.1	<.1	9.3	7.3	38
				111	32	130	.4	.81	90	1230	120	15.4	3.7	.26	<.1	11.2		
				84	44	130	.3	.44	40	640	130	8.3	4.2	.11	<.1	6.2	7.2	

Table 57. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 31
Date: 11/14/72

Time (hrs) From Storm Start	Last Storm	Last Peak	Q CFS	Organics mg/1 COD	TOC	BOD	Nutrients mg/1 K-N	Total P	Fecal Coliforms #/ml	Solids mg/1 Total	VS	SS	VSS	Metals mg/1 Co	Cu	Fe	Pb	Zn	pH	ALK mg/1 CaCO$_3$
.8	141	141	112	303	74	210	.4	2.4	700	2300	360	220	28	<.1	.11	21.4	.89	.88	7.3	68
1.2	141	.5	80	223	72	170	.3	1.1	170	1240	300	106	21	<.1	<.1	20.9	.51	.49		
1.5	142	.8	96	169	58	150	.3	.83	210	1560	240	136	18	<.1	<.1	15.0	.38	.38	7.0	27
3.5	144	2.7	28	81	43	34	.4	.77	320	780	220	59	12	<.1	<.1	13.3	.11	.20		
3.7	144	2.9	25	104	42	34			250	920	250	58	7	<.1	<.1	36.9	.15	.27	7.2	26
4.0	144	3.2	18	73	33	30	.3	.61	260	510	200	30	13	<.1	<.1	13.1	.14	.19		
4.1	144	3.3	17	85	44	30	.4	.58	200	660	230	44	9	<.1	<.1	15.8	.13	.20	7.1	30
4.5	145	3.7	14	61	34	34	.3	.52	160	440	190	27	10	<.1	<.1	9.5	.14	.14		
4.7	145	3.9	8	88	40	24	.4	.39	190	1040	190	66	11	<.1	<.1	12.9	.10	.24	7.2	34

Table 58. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 32
Date: 11/19/72

Time (hrs) From			Q CFS	Organics mg/l		Solids mg/l				Metals mg/l				
Storm Start	Last Storm	Last Peak		COD	TOC	Total	VS	SS	VSS	Co	Cu	Fe	Pb	Zn
0.1	59	59	2	268	33					<.10	<.10	17.0	.44	.72
0.2	59	59	4	105	37	700	164	347	84	<.10	<.10	15.6	.30	.29
0.5	60	60	5	109	34	578	67	286	61	<.10	<.10	18.5	.23	.24
1.0	60	60	7	112	38	906	87	674	83	<.10	<.10	16.9	.35	.28
1.5	61	61	7	62	33	614	117	344	110	<.10	<.10	20.8	.37	.29
2.0	61	61	8	66	26	576	103	442	116	<.10	<.10	12.0	.22	.17
2.5	62	62	9	58	15	479	132	303	89	<.10	<.10	12.8	.24	.17
3.0	62		8	58	30	405	172	118	74	<.10	<.10	18.2	.22	.17
3.5	63		7	74	31	612	130	318	102	<.10	<.10	14.0	.24	.20
4.0	63		6	70	22	703	141	342	108	<.10	<.10	18.4	.14	.20
4.5	64		6	62	21	408	92	127	61	<.10	<.10	10.7	.13	.14
5.0	64		8	194	57	1659	160	1225	232	<.10	<.10	44.5	.42	.48
5.5	65		10	101	37	1510	158	807	117	<.10	<.10	35.5	.44	.27
6.0	65		12	74	38	1283	117	1005	148	<.10	<.10	16.0	<.10	.25
6.5	66		14	109	36	2176	149	1000	128	<.10	<.10	17.8	.14	.27
7.0	66		13	78	50	878	163	614	81	<.10	<.10	19.7	<.10	.29
7.5	67		10	350	49	1984	253	1759	243	<.10	<.10	29.5	.51	.52
8.0	67		43	136	34	2726	164	2439	197	<.10	<.10	26.5	.36	.41
8.5	68		73	78	30	600	107	321	124	<.10	<.10	20.3	.11	.17
26	85		3	35	22	309	98	88	86	<.10	<.10	4.3	<.10	.19

Table 59. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 33
Date: 11/30/72

Time (hrs) From			Q CFS	Organics mg/1			Nutrients mg/1		Fecal Coliform	Solids mg/1				Metals mg/1					ALK mg/1 as $CaCO_3$	pH
Storm Start	Last Storm	Last Peak		COD	TOC	BOD	K-N	Total P	#/ml	Total	VS	SS	VSS	Cd	Cu	Mn	Sr	Zn		
9.5	111.0	6.5	0.9	124	38	99	.3	.59	32	1910	269	1416	184	<.10	.15	.36	<.10	.33		
10.0	111.5	7.0	0.9	95	31	54	.3	.60	28	1868	263	1514	144	<.10	<.10	.43	<.10	.29	42	7.1
10.5	112.0	7.5	1.0	84	30	48	.2	.46	29	790	257	514	100	<.10	.14	.44	<.10	.25		
11.0	112.5	8.0	1.4	148	60	80	.1	1.10	54	2147	325	1803	187	<.10	.13	.54	<.10	.42	38	7.0
11.5	113.0	0.5	1.2	133	56	46	.2	.73	96	2020	320	1510	176	<.10	.16	.51	<.10	.33		
12.0	113.5	1.0	[illegible].1	76	24	40	.2	.53	51	1043	257	762	135	<.10	.11	.57	<.10	.22	32	7.0
12.5	114.0	1.5	1.0	68	36	36	.2	.51	55	805	187	635	155	<.10	<.10	.33	<.10	.23		
13.0	114.5	2.0	1.0	83	46	36			32	852	218	632	153	<.10	.11	.28	<.10	.23	36	7.5
13.5	115.0	2.5	1.0	68	38	36	.2	.67	22	1450	222	1704	152	<.10	<.10	.45	<.10	.33		
14.0	115.5	3.0	1.0	72	34	34	.2	.48	23	1215	[illegible]35	710	135	<.10	<.10	.42	<.10	.27	40	7.3
14.5	116.0	3.5	.9	99	56	32	.2	.53	62	2219	289	1752	174	<.10	.12	.46	<.10	.29		
15.0	116.5	4.0	.8	65	12	44	.2	.48	45	1641	277	2006	44	<.10	<.10	.51	<.10	.26	42	7.3

Table 60. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 34
Date: 1/19/73

Time (hrs) From			Q CFS	Organics mg/l			Nutrients mg/l		Solids mg/l				Metals mg/l							ALK mg/l as $CaCO_3$	pH
Storm Start	Last Storm	Last Peak		COD	TOC	BOD	K-1	Total-P	Total	VS	SS	VSS	Al	Co	Cr	Cu	Mg	Ni	Pb		
.05	101	101	3.0	304	108	62	1.0	1.9	2351	208	2492	149	17.9	<.10	.13	<.10	14.8	<.10	1.11	74	7.2
.10	101.1	101.1	3.2	312	57	54			5453	201	4844	170	27.6	<.10	.18	.10	21.7	<.10	1.08		
.15	101.2	101.2	3.2	324	89	50	.7	2.5	3646	184	3179	131	20.1	<.10	.13	.10	15.2	<.10	1.04		7.5
.20	101.2	101.2	3.0	254	60	46			1001	122	603	76	14.0	<.10	.12	<.10	13.4	<.10	.87		
.25	101.2	101.2	2.9	250	63	42	.7	1.0	999	118	581	80	12.6	<.10	.13	<.10	12.6	<.10	.75	74	7.3
.30	101.3	101.3	2.9	241	60	42			1025	129	581	86	11.7	<.10	<.10	<.10	13.4	<.10	.84		
.35	101.4	101.4	2.9	237	64	40	.8	1.1	1005	129	583	85	12.3	<.10	<.10	<.10	12.6	<.10	.76		7.9
.40	101.4	101.4	2.9	241	72	40			962	121	567	79	11.5	<.10	<.10	<.10	12.6	<.10	.75		
.45	101.4	101.4	3.0	250	80	42	.7	1.0	972	118	645	83	16.5	<.10	.13	<.10	13.7	<.10	.86	74	7.2
.50	101.5	101.5	3.2	283	100	38			1204	153	775	95	17.6	<.10	.16	<.10	13.8	<.10	.96		
.55	101.6	101.6	3.3	366	81	42	.6	1.2	1446	232	1055	158	18.5	<.10	.13	<.10	14.1	<.10	1.09		7.1
.60	101.6	101.6	3.3	354	107	36			1470	237	1063	132	18.6	<.10	.14	<.10	16.2	<.10	1.05		
.65	101.6	101.6	3.5	358	113	38	.6	1.2	1541	251	1140	191	18.2	<.10	.13	.10	13.6	<.10	1.05	66	7.2
.70	101.7	101.7	3.5	349	100	38			1532	239	1224	183	17.5	<.10	.16	<.10	13.8	<.10	1.02		
.75	101.8	101.8	3.6	379	108	40	.5	1.3	1615	278	1330	185	19.2	<.10	.18	.10	13.2	<.10	1.17		7.5
.80	101.8	101.8	3.8	387	89	42			1676	264	1403	191	20.4	<.10	.15	<.10	15.3	<.10	1.14		
.85	101.8	101.8	4.5	379	106	42	.6	1.2	1900	404	1582	206	21.0	<.10	.17	<.10	14.8	<.10	1.39	62	7.2
.90	101.9	101.9	4.7	428	144	48			1639	420	1328	212	22.1	<.10	.15	<.10	16.0	<.10	1.36		
.95	102.0	102.0	5.2	445	174	52	.6	1.9	1849	424	1441	215	22.2	<.10	.17	.11	17.0	<.10	1.59		7.2
1.00	102.0	102.0	5.5	478	147	58			2027	455	1609	226	23.7	<.10	.18	.12	19.2	<.10	1.65		
1.05	102.1	102.1	8.5	457	139	62	.7	1.7	1984	413	1658	235	25.6	<.10	.18	.11	16.1	<.10	1.49	74	7.2
1.10	102.1	102.1	10.5	494	120	62			2095	453	1713	232	24.1	<.10	.20	.12	20.0	<.10	1.54		
1.15	102.2	102.2	18.0	511	177	68	.9	2.4	1958	445	1601	348	25.4	<.10	.20	.14	16.4	<.10	1.44		7.1
1.20	102.2	102.2	18.0	560	90	74			2199	477	1839	415	26.7	<.10	.21	.18	19.0	<.10	1.67		
1.25	102.2	102.2	18.0	515	152	70	.8	1.7	1878	468	1559	352	25.0	<.10	.23	.15	16.9	<.10	1.69	62	7.0
1.30	102.3	102.3	20.0	556	132	66			1949	457	1635	378	26.5	<.10	.22	.12	18.6	<.10	1.77		

Table 61. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 35
Date: 2/26/73

Time (hrs) From			Q CFS	Organics mg/1			Solids mg/1				Metals mg/1						ALK mg/1 as $CaCO_3$	pH
Storm Start	Last Storm	Last Peak		COD	TOC	BOD	Total	VS	SS	VSS	Al	Co	Cr	Cu	Ni	Pb		
0.5	290	290	32	227	84	100	1085	255	867	129	7.3	<.10	<.10	<.10	<.10	.65	74	7.52
0.7	290.2	290.2	58	234	92	80	1086	261	858	147	7.6	<.10	<.10	<.10	<.10	.58	72	7.47
0.9	290.4	290.4	71	406	120	120	1532	335	1361	133	13.4	<.10	.11	.13	<.10	.85	76	7.37

Table 62. TIME PARAMETERS AND ANALYTICAL RESULTS OF URBAN RUNOFF EVENT NUMBER 36
Date: 3/21/73

Time (hrs From			Q CFS	Organics mg/1		Nutrients mg/1		Fecal Coliforms	Solids mg/1				Metals mg/1						ALK mg/1 as $CaCO_3$	pH
Storm Start	Last Storm	Last Peak		COD	TOC	K-N	Total P	/ml	Total	VS	SS	VSS	Al	Co	Cr	Cu	Ni	Pb		
.33	98	98	28	144	46	.4	.92	450	684	230	599	130	7.2	<.10	<.10	<.10	<.10	.23	48	7.2
.50	98.2	98.2	35	136	42	.8	.69	400	603	198	509	114	6.6	<.10	<.10	<.10	<.10	.28		
.67	98.3	98.3	37	116	66	.6	.73	350	652	183	581	96	7.4	<.10	<.10	<.10	<.10	.48	29	7.0
.84	98.5	98.5	38	124	44	.6	.78	350	1150	225	1256	102	9.6	<.10	<.10	<.10	<.10	.30		
1.01	.2	98.7	35	140	36	.3	.70	350	943	209	894	148	9.6	<.10	<.10	<.10	<.10	.23	24	6.8
1.18	.3	98.8	31	101	27	.5	.61	300	888	144	799	119	9.1	<.10	<.10	<.10	<.10	.29		
1.35	.7	99.2	23	82	22	.4	.58	300	653	178	510	85	7.6	<.10	<.10	<.10	<.10	.31	28	6.9
1.52	.8	99.4	18	89	33	.4	.39	300	661	169	611	105	7.9	<.10	<.10	<.10	<.10	.25		
1.69	1.0	99.5	14	74	20	.4	.48	250	651	184	495	96	6.7	<.10	<.10	<.10	<.10	.26	28	7.0
1.86	1.2	99.7	12	82	25	.4	.47	180	587	144	505	89	7.2	<.10	<.10	<.10	<.10	.20		
1.03	1.4	99.9	9	70	21	1.0	.48	170	543	144	431	91	6.7	<.10	<.10	<.10	<.10	.16	30	7.0
1.20	1.5	100.0	7	74	38	.4	.55	160	709	137	655	98	7.3	<.10	<.10	<.10	<.10	.23		
1.37	1.7	100.2	7	58	19	.4	.46	140	685	153	574	85	6.3	<.10	<.10	<.10	<.10	.22	30	7.2
1.54	1.9	100.4	6	62	16	.4	.47	140	697	193	688	98	6.7	<.10	<.10	<.10	<.10	.15		
1.71	2.0	100.6	6	62	19	.4	.52	140	682	188	525	103	6.7	<.10	<.10	<.10	<.10	.15	32	7.1
1.88	2.4	100.9	4	58	18	.4	.52	150	715	146	652	99	6.0	<.10	<.10	<.10	<.e0	.20		

Table 63. THIRD FORK CREEK BASE FLOW OBSERVATIONS AT U.S.G.S. GAGE HOUSE

Date	Q CFS	D.O. mg/1	Temp. °C	Organics mg/1			Nutrients mg/1		Fecal Coliform	Solids mg/1				Metals mg/1												ALK mg/1 as $CaCO_3$	pH
				COD	TOC	BOD	K-N	Total-P	#/ml	Total	VS	SS	VSS	Al	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
11/1/71	2.8			29		11	5.0	.6	4	380		41				.44		.35	.7								
11/8/71	1.7			32		4	5.6	.34	5	400		30				.54		.86	2.5								
11/12/71	1.2			72		26	9.0	.63		525		18				.44		.34	1.4								
11/16/71	1.2		14	25			5.5	.65		360		20				.38		.79	1.1								
11/19/71	1.3	4.6	15	29			2.7	.97		480		20						.35	2.2								
11/20/71	1.2	6.4	10.5	7			3.6	.95		375		25				.4		.33	1.8								
12/2/71	.7	8.4	7.0	12	15		1.4	.45		530		100				.14	.23	.10	1.2		.55	.16					
12/13/71		6.7	15	36	14		1.7	.35	46	330		65				.24	.10	.11	1.9		.49	.24	.5		<.10		
12/14/71				61	24	19	1.6	.64		335		5				.17	.26	.11	1.3		.87	.21	.3		.18		7.9
12/16/71	.6			10	5		4.7	.7	91	435						.03	.30	<.10	.9		.69	.24	.28		.12		7.5
12/16/71	.7			38	5		4.6	.7	114	650						.17	.24	<.10	1.2		.53	.13	.29		.14		7.3
12/21/71	1.7		14		6		6.2	.24	155							.21	.37	<.10	1.4		.47	.12	.53		<.10		7.6
1/5/72			14	56	5	12	1.2	.8	340	260		55			12.5		.25		3.4	10.8	.42		.45		.13		7.5
1/19/72				27	14	2	2.9	.4	30							.18	.14	<.10	2.1		.66	.12	.31		<.10		7.6
1/26/72			11	12	18	3	2.9	.02	8						26.0		.22		1.5	14.8	.68		.39		.17		7.9
2/9/72	.9	10.0	6	12	1	1	.9	.35	9	340					34.4		.25		1.6	17.2	.76		.26		.26		7.9
3/15/72	.9	12.8	18.5	35	15	2	.5	1.0		380	55				31.1				1.9	12.2	.36		.15		.16		8.9
3/23/72	.9	8.7	16	8	10	3	.4	.22	4	315	60				42.1				1.6	14.0	.38		.14		<.10		8.0
3/30/72	.6	9.5	15	23	18	4			1	335	40				28.0				1.5	12.0	.39		<.10		.13		7.8
4/19/72	.7	9.2	25	23	22	14	.4	.67	2	345	95	4	4				<.1	<.1					<.10		<.10	150	8.6
4/26/72		7.0		12	19	3	.3	.27	5	325	75	25					<.1	<.1					<.10		.06	124	8.1
6/8/72	.5	10.6	29	22	10	14	.3	.83	23	445	70	60				<.10			1.1		.20	<.10	<.10			136	8.5
7/11/72				31	24	15	.3	.69	23	455	70	15								10.5	.74				.34	124	7.9
7/26/72	.5	9.0	29	35	4	10	.5	1.1	12	480	155	5	5		33.2		<.1	<.1		6.2					.24	149	8.2
8/21/72	.4	7.0	27	22	17		.5	.65	81	505	40	50	10						1.0		.20		<.10	.37		119	7.8
9/13/72			28	19	15	14	.4	.98	57	375	75	20							.8		<.10		<.10	<.10		137	8.6
10/12/72	.7	7.7	17	50		12	.3	.36	97	675	145	330	80	13.6	4.5		<.1	<.1		11.8						86	7.6
11/2/72	.5	5.5	20.5	50	18	42	.5	1.3	6	365	105					<.1		<.1	.9				<.10		.48	[illegible]	7.6
11/10/72	.5	7.2	16	38	26	44	.2	.35	17	335	105					<.1		<.1	.9				<.10		.12	142	7.7
1/25/73	.5	10.5	7.8	24	6	54	1.3	.26	55	270	137			.7		<.1	<.1	<.1		8.7		<.10	.11			104	7.6
3/1/73	.8	10.2	11	19	13	13	1.2	.25	22	254	103	15	15	.3		<.1	<.1	<.1				<.10	.14			93	7.3
3/20/73	.8	9.4	12.5	24	21	42	.4	.23	15	367	116	72	37	.3		<.1	<.1	<.1				<.10	.14			112	7.6
MEAN	.9	8.4	16.5	29	14	15	2.2	.57	49	400	90	50	25	3.75	26.5	.26	.23	.27	1.5	11.8	.52	.16	.26	.37	.16	122	7.9
STD. DEV.	.5	2.0		16	7	15	2.3	.31	73	106	36	73	29	6.66	12.3	.15	.07	.27	.6	3.1	.19	.05	.14	0	.11	19	.4

Table 64. SUB-BASIN E-1 BASE FLOW OBSERVATIONS

Date	D.O. mg/l	Temp. °C	Organics mg/l			Nutrients mg/l		Fecal Coliform	Solids mg/l				Metals mg/l												ALK mg/l as $CaCO_3$	pH
			COD	TOC	BOD	K-N	Total-P	#/ml	Total	VS	SS	VSS	Al	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
12/14/71			20	12	2	1.3	.05		295		5				<.10	.23	.10	2.2		.81	.15	.20		<.1		7.6
12/21/71				12		5.3	.06	10							.10	.27	.10	2.1		.56	.12	.33		.11		7.8
1/5/72			60	21	10	1.1	.10	53	305		40			22.8		.21		4.6	9.9	.58		.34		<.10		7.4
1/19/72			20	15	1	3.2	.08	1							<.10	.27	.11	2.0		.68	.30	.30		<.10		7.5
1/26/72			15	13	2	2.5		4						40.1		.28		1.5	16.4	.93		.39		<.10		7.9
2/9/72	10.6	6.0	12	8	<1	.7	.02	2	300					38.4		.29		1.8	14.4	.95		.39		<.10		7.9
3/15/72	10.2	13.5	8	10		.6	.10	10	340	60				56.5				2.6	13.2	1.05		.14		<.10		7.6
3/23/72	8.7	12.0	8	10	2	.5	.07	1	330	65				46.4				2.9	14.6	.83		.28		<.10		7.7
3/30/72	8.3	12.0	23	10	2			1	310	45				44.8				2.0	12.2	.92		<.10		<.10		7.5
4/19/72	7.8	10.5	12	31	8	.3	.06	2	335	90	4	4				<.10	<.10					<.10		<.10	190	7.7
4/26/72	7.8		12	26	2	.4	.06	10	325	85	15					<.10	<.10					<.10		<.10	170	7.8
6/8/72	7.4	19.5	6	12	13	.3	<.05	5	385	85					<.10			.8		2.69	<.10	<.10			224	8.3
7/11/72			66	50	20	1.1	.47	54	950	165	580								20.5	3.96				.16	244	7.8
7/26/72	5.7	22.0	36	12	9	.9	.16	3	435	185				53.9		<.10	<.10		9.2					<.10	249	7.9
8/21/72	6.2	21.0	19	19		.4	<.05	4	315	40	20	5						1.7		.78			.29		177	7.8
9/13/72		18.0	23	15	13	.6	.27	5	440	100	25							5.3		2.01		<.10	.57		262	7.9
10/12/72	8.4	14.5	16	21	20	.5	<.05	1	345	140	40	40	.78	49.2		<.10	<.10		16.2						186	8.0
11/2/72	8.2	16.0	23	18	20	.4	<.05	1	310	110					<.10		<.10	1.0				<.20		<.10	188	7.7
11/10/72	8.4	12.5	23	20	17	.3	.05	2	315	90					<.10		<.10	1.6				<.10		<.10	154	7.8
1/25/73	11.8	6.5	12	15	24	.5	.16	.4	235	92			.70		<.10	<.10	<.10		7.6		<.10	<.10			102	7.8
3/1/73	11.3	10.0	19	14	7	.4	.07	.3	266	126	8	8	.65		<.10	<.10	<.10				<.10	.23			85	7.
3/20/73	11.2	10.5	16	10	10	.3	.06	.1	262	83			.49		<.10	<.10	<.10				<.10	.20			128	7.8
MEAN	8.8		21	17	10	1.02	.10	8	358	98	82	14	.66	45.0	.10	.25	.10	2.3	13.4	1.3	.19	.27	.43	.13	181	7.7
STD.DEV.	1.9		15	9	8	1.22	.10	15	152	40	187	17	.12	10.5	0	.03	0	1.3	3.9	1.0	.09	.08	.20	.03	55	.2

Table 65. SUB-BASIN E-2 BASE FLOW OBSERVATIONS

Date	D.O. mg/l	Temp. °C	Organics mg/l			Nutrients mg/l		Fecal Coliform	Solids mg/l				Metals mg/l												ALK mg/l as $CaCO_3$	pH
			COD	TOC	BOD	K-N	Total-P	#/ml	Total	VS	SS	VSS	Al	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
12/14/71			14	12	2	5.40	.26		340		5				.18	.23	.11	1:2		.79	.12	.30		<.10		
12/21/71				8		2.15	.12	265							.13	.23	.14	1.6		.35		.33		<.10		7.8
1/5/72			68	11	8	.60	.13	21	340		60			18.1		.20		3.9	11.0	.28		.36		.17		7.7
1/19/72			27	14	2	3.6	.23	78							<.10	.18	<.10	1.3		.62	.18	.33		<.10		7.8
1/26/72			15	13	4	4.25	.25	7						48.7		.26		1.7	21.8	.83		.09		<.10		7.8
2/9/72		5	16	<1	<1	2.5	.28	53	415		10			41.2		.28		2.0	20.6	.78		.16		.15		7.9
3/15/72		17	54	18	0.3	.4	.33		415	70				44.2				2.2	17.8	.45		.26		.12		9.0
3/23/72		13	8	12	2	.3	.08	3	415	115				46.9				1.6	16.0	.51		.29		.12		7.8
3/30/72		14	12	30	4			1	380	60				48.3				.8	23.6	.63		<.10		.10		8.0
4/19/72		24	4	28	9	.2	.19	.2	380	120	2	2				<.10	<.10					<.10		<.10	172	8.2
4/26/72			12	22	1	.3	.11	3	370	110						<.10	<.10					<.10		<.10	156	7.8
6/8/72		24	20	8	13	.3	.06	6	435	85	5				<.10			.7		.66	<.10	<.10			168	8.1
7/11/72			35	18	12	.4	.74	80	465	50	40								9.0	.36				.27	98	7.7
7/26/72	6.7	28.0	69	5	18	.3	.27	34	465	220	10	10		28.8		<.1	<.1		14.4					.19	157	8.0
8/21/72	6.8	25.0	7	6		.2	.06	2	340	50	20	15						.4		.17		<.10	.47		149	7.9
9/13/72		24.5	15	12	15	.3	.16	1	315	65	20							.4		.12		<.10	.23		153	7.9
10/12/72	6.3	14.5	23		19	.2	.12	1	430	115	35	35	.25	84.1		<.1	.25		24.8						196	7.8
11/2/72	6.7	18.0	23	15	17	.2	.18	9	325	115					<.1		<.1	1.0				<.10		<.10	85	7.8
11/10/72	7.5	14.0	19	2	14	.1	.1	0.5	395	125					<.1		<.1	1.0				<.10		<.10	170	7.8
1/25/73	10.6	5.5	20	11	19	.2	.1	1	416	164			1.30		<.1	<.1	<.1		17.7		<.10	<.10			166	7.9
3/1/73	11.2	8.0	30	13	14	.2	.09		397	140	20	20	.17		<.1	<.1	<.1				<.10	.14			140	7.9
3/20/73	10.8	10.2	16	18	20	.2	.18	.3	406	111			.39		<.1	<.1	<.1				<.10	.19			182	7.9
MEAN	9.7		24	13	10	1.05	.19	30	392	107	21	16	.53	45.0	.15	.21	.16	1.4	17.7	.50	.15	.24	.35	.15	153	7.9
STD.DEV.	3.0		16	8	7	1.55	.14	63	44	45	18	12	.52	19.1	.03	.05	.07	.9	5.2	.23	.04	.09	.17	.05	31	.3

Table 66. SUB-BASIN N-2 BASE FLOW OBSERVATIONS

Date	D.O. mg/1	Temp. °C	Organics mg/1			Nutrients mg/1		Fecal Coliform	Solids mg/1				Metals mg/1												ALK mg/1 as $CaCO_3$	pH
			COD	TOC	BOD	K-N	Total P	#/ml	Total	VS	SS	VSS	Al	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
12/14/71			68	24	21		.52		375		40				.10	.37	.14	1.4		.56	.14	.30		.31		7.4
12/21/71				16		4.8	.61	220							<.10	.38	<.10	1.9		.52	.17	.30		.23		7.5
1/5/72			176	14	42	.7	.33	87	310		30			12.3		.25		2.2	16.5	.37		.23		.21		7.1
1/19/72			38	28	2	9.0	1.48	21							<.10	.31	<.10	1.9		.69	.22	.30		.19		7.3
1/26/72			88	32	26	2.5	2.4	2						13.5		.32		1.2	13.4	.48		.28		.20		8.1
2/9/72		12.0	16	23	3	.9	1.85	16	510		25			13.0		.35		1.7	12.8	.52		.12		.65		7.7
3/15/72		21.0	31	21		.5	3.20	1	375	40				17.9				1.4	7.0	.25		<.10		.25		9.2
3/23/72		18.0	50	21	15	.8	3.10	3	900	95	10	10		36.7				1.6	17.0	.27		<.10		.52		9.0
3/30/72		17.0	19	13	4			2	395	55				18.0				1.4	10.4	.32		.13		.24		8.6
4/19/72		26.5	35	41	13	.5	3.10	4	380	120	8	8				<.10	<.10					<.10		.23	136	9.2
4/26/72			19	24	2	.2	1.50	3	380	95	50	5				.18	<.10					<.10		.22	96	7.2
6/8/72		27.0	47	20	18	.5	2.30	110	430	85					<.10			.6		1.20	<.10	<.10			128	8.3
7/11/72			14	20	7	.2	.10	1	295	75	35								12.3	.18				<.10	134	8.2
7/26/72	3.6	30.0	84	22	24	.5	1.8	3	770	165	15	15		26.8		.11	<.10		6.8					.34	145	8.0
8/21/72	5.4	29.0	26	10		.5	1.2	4	375	25	25	10						.9		.35		<.10	.10		107	7.8
9/13/72		29.5	549	178	85	.5	2.2	4	375	105	10							.6		<.10		<.10	<.10		117	8.0
10/12/72	4.6	21.0	50	20	13	.6	1.5		505	130	60	60	.87	29.3		<.10	<.10		9.2						116	8.2
11/2/72	4.5	23.0	115	30	62	.7	2.6	3	350	135	15	15			<.10		<.10	2.1				<.10		2.70	49	7.4
11/10/72	5.8	20.0	72	24	27	.5	2.7	140	410	135	15	15			<.10		<.10	1.5				<.10		.76	124	7.6
1/25/73	6.7	14.2	44	22	26	1.6	1.5	140	414	139	20	20	1.50		<.10	<.10	<.10		7.2		<.10	.15			65	7.4
3/1/73	9.3	15.0	69	26	26	1.6	2.6	12	365	131	24	24	.74		.10	<.10	<.10				<.10	.18			76	7.3
3/20/73	5.1	15.5	99	19	73	.9	.92	240	218	99			.57		<.10	<.10	<.10				<.10	.15			78	7.3
MEAN	7.5		81	29	25	1.39	1.78	51	428	102	25	18	.92	20.9	.10	.30	.14	1.4	11.2	.47	.17	.21	.10	.51	105	7.9
STD.DEV.	3.2		114	34	24	2.07	.94	78	159	39	15	16	.40	9.0	0	.07	0	.5	3.8	.27	.04	.07	0	.68	30	.6

Table 67. SUB-BASIN W-1 BASE FLOW OBSERVATIONS

Date	D.O. mg/l	Temp °C	Organics mg/l			Nutrients mg/l		Fecal Coliform	Solids mg/l				Metals mg/l												ALK mg/l as $CaCO_3$	pH
			COD	TOC	BOD	K-N	Total-P	#/ml	Total	VS	SS	VSS	Al	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
12/14/71			28	14	2	6.4	.42		275						.20	.30	.11	1.2		.46	.23	.50		<.10		7.7
12/21/71				10		4.5	.34	35							.15	.16	.10	1.8		.51	.22	.30		<.10		7.8
1/5/72			36	16	2	2.8	.47	70	195		15			18.2		.22		1.3	9.4	.26		<.10		<.10		7.7
1/19/72			20	14	3	3.8	1.48	102							.05	.29	.14	1.9		.83	.12	.20		<.10		7.6
1/26/72			8	12	4	2.5	.25	15						27.8		.27		1.5	14.4	.57		.11		<.10		7.9
2/9/72		6.0	12	1	<1	0.7	.06	2	260		10			27.2		.17		1.6	16.0	.59		.13		<.10		7.9
3/15/72		17.5	4	17	1	0.6	.07		265	40				35.9				1.7	8.2	.31		<.10		<.10		7.8
3/23/72		14	4	10	2	0.5	.06	2	240	65				44.2				1.5	13.6	.19		<.10		<.10		7.9
3/30/72		14	4	8	2				245	40				22.2				1.2	16.0	.19		.12		<.10		7.9
4/19/72		23	12	28	8	0.4	.21	2	260	115	4	4				<.10	<.10					<.10		<.10	124	7.7
4/26/72			19	28	4	0.4	.18	4	270	95	10	5				<.10	<.10					<.10		<.10	116	7.8
6/8/72		26.0	35	9	10	0.3	.11	34	280	65	5				<.10			.9		.69	<.10	<.10			126	8.1
7/11/72			25	20	11	0.9	.36	150	300	45	105								9.9	.24				<.10	132	7.9
7/26/72	6.1	26.0	27	8	10	2.4	.83	140	235	140	10	10		26.8		<.10	<.10		5.6					<.10	122	7.8
8/21/72	6.8	25.0	108	21		1.4	.62	480	240	25	25	10						.9		.25		<.10	.30		113	7.7
9/13/72		25.0	19	16	15	.8	.84	420	240	45	10							.4		<.10		<.10	.20		128	7.9
10/12/72	7.6	16.0	19	8	20	.9	.52	650	275	115	40	40	.13	28.7		<.10	<.10		12.5						106	7.8
11/2/72	6.8	18.5	15	12	17	.5	.26	120	220	105					<.10		<.10	.4				<.10		<.10	113	7.9
11/16/72	8.3	14.5	15	21	12	.2	.06	10	250	90	5	5			<.10		<.10	.6				<.10		<.10	106	7.8
1/25/73	11.0	7.0	16		16	.4	.05	1	240	124			1.10		<.10	<.10	<.10		9.8		<.10	.17			90	7.9
3/1/73	11.0	10.0	15	2	2	.1	.06	2	223	104	2	2	.18		<.10	<.10	<.10				<.10	.14			84	7.6
3/20/73	10.4	12.7	12	12	12	.2	.05	25	228	78			.13		<.10	<.10	<.10				<.10	.13			102	7.8
MEAN	8.8	17.0	22	15	8	1.46	.34	119	250	81	20	11	.38	28.9	.13	.23	.11	1.2	11.4	.42	.19	.18	.25		112	7.8
STD DEV.	1.8		22	7	6	1.68	.35	188	25	35	29	13	.48	8.0	.07	.06	.02	.5	3.7	.21	.06	.12	.07		15	.1

Table 68. SUB-BASIN W-2 BASE FLOW OBSERVATIONS

Date	D.O. mg/1	Temp. °C	Organics mg/1			Nutrients mg/1		Fecal Coliform	Solids mg/1				Metals mg/1												ALK mg/1 as $CaCO_3$	pH
			COD	TOC	BOD	K-N	Total-P	#/ml	Total	VS	SS	VSS	Al	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
12/14/71			25	16	2	8.4	.85		260		5				<.10	.34	.11	2.2		.71	.16	.30		<.10		7.6
12/21/71				16		10.0	.85	380							.17	.37	.11	7.2		.59	.25	.28		.12		7.5
1/5/72			56	24		17.0	2.40	805	285		90			12.3		.23		3.4	9.5	.46		.10		.13		7.1
1/19/72			24	14	1	3.5	.59	95							.18	.26	<.10	2.3		.49	.20	.31		<.10		7.4
1/26/72			22	16	5	4.0	.42	3						27.6		.30		10.8	13.7	.65		.20		<.10		7.6
2/9/72		5.0	20	1	<1	1.0	.06	4	280		10			31.8		.21		1.9	14.4	.58		.10		<.10		7.8
3/15/72		18.0	8	16	0.5	.5	.20	5	280	45				35.2				2.6	10.4	.11		.23		<.10		8.5
3/23/72		13.0	12	11	2	1.3	.08	11	365	65	5	5		32.2				2.0	12.2	.28		.31		<.10		7.9
3/30/72		13.0	8	10	2			1	260	50				24.2				1.5	12.6	.13		<.10		<.10		8.5
4/19/72		22.5	8	20	8	.40	.10	0.5	255	100	4	4				<.10	<.10					<.10		<.10	114	8.9
4/26/72			12	22	1	.4	.08	2	285	90	10	5				<.10	<.10					<.10		<.10	126	7.7
6/8/72		19.0	18	8	14			6	395	60	45				<.10			2.7		.28	<.10	<.10			156	8.0
7/11/72			23	32	8	.3	.06	13	330	45	20								11.1	.19				<.10	156	8.2
7/26/72	8.5	24.0	31	4	8	.3	.09	4	290	150				36.6		<.10	<.10		7.8					<.10	163	8.1
8/21/72	7.8	23.0	19	15		.3	.07	24	245	25	20	10						.4		<.10		<.10	.27		140	8.0
9/13/72		23.0	12	15	13	.2	.10	9	200	35	10							.8		<.10		<.10	.16		104	7.9
10/12/72	10.0	15.0	12	13	8	.3	.05	3	310	100	25	25	.3	43.7		.14	<.10		26.0						142	7.5
11/2/72	9.0	17.0	15	36	17	.2	.05	.6	240	95					<.10		<.10	.5				<.10		<.10	130	8.1
11/10/72	8.6	14.0	19	20	12	.3	.05	3	275	105					<.10		.22	.7				<.10		<.10	120	7.8
1/25/73	9.5	9.5	202	40	138	3	8		376	190	51	51	1.8		<.10	<.10	<.10		6.6		<.10	.13			114	7.1
3/1/73	11.3	8.0	19	14	22	.3	.14		290	123	14	14	.19		<.10	<.10	<.10				<.10	<.10			124	7.5
3/20/73	10.4	11.0	16	12	78	.4	.05	1	269	83			.24		<.10	<.10	<.10				<.10	.16			150	7.6
MEAN	9.9		28	17	18	2.6	.71	72	289	85	24	16	.63	30.4	.18	.26	.14	2.8	12.4	.40	.20	.19	.22	.11	134	7.9
STD.DEV.	1.6		41	9	34	4.4	1.80	198	49	44	25	17	.78	9.4	0	.07	.06	2.9	5.4	.21	.04	.08	.08	.01	19	.5

Table 69. ANALYTICAL RESULTS OF URBAN RUNOFF FROM SUB-BASIN E-1

Storm No.	Q CFS	Sample Time Military	Organics mg/1			Nutrients mg/1		Fecal Coliform	Solids mg/1				Metals mg/1												ALK mg/1 as $CaCO_3$	pH
			COD	TOC	BOD	K-N	Total-P	#/ml	Total	VS	SS	VSS	Al	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
19	0.034	1555	67	19	15	.8	.44	800	405	75	275	55			<.10			10.6		.81	<.10	.53			58	7.1
	0.034	1620	49	15	12	.6	.29	750	320	65	165	45			<.10			4.8		.60	<.10	.29				
	0.027	1646	33	12	11	.5	.18	500	265	60	80	30			<.10			3.1		.37	<.10	.10				
20		1417	24	40		.4	.14				115	20			<.10			9.9		2.71	<.10	.11				
	.26	0405	138	48		.9	.69	470	395	170	320	55			<.10			17.1		.79	<.10	.34			50	7.0
	.03	0520	86	26		.8	.14	1200			90	20			<.10			1.8		.33	<.10	.10				
	.46	0650	106	29		.5	.56	960	355	145	285	45			<.10			17.3		.65	<.10	.25				7.1
	.22	0720	170	49				2200			865	135			<.10			25.8		2.58	<.10	.68				
	.30	0805	102	46		.5	.85	870	615	185	580	75			<.10			20.0		.51	<.10	.30			32	6.9
	.12	0835	54	22				330			235	25			<.10			5.5		.29	<.10	.17				
	.06	0935	54	14		.6	.22	220	300	95	170	15			<.10			3.9		.25	<.10	.13				7.3
	.12	1035	88	31							195	20			<.10			4.5		.21	<.10	.19				
25	1.0	1434	78	31	58	.3	.52		1220	210	1100	180		1.0		<.10	<.10		5.0					.31	13	6.4
	.85	1454	97	36	50	.2	.44		750	200	600	130		3.0		.11	<.10		6.0					.34		
	2.30	1512	344	18	48	.2	.61		1790	300	1700	210		1.1		.13	<.10		7.2					.42		6.5
	1.60	1528	54	17	48	.2	.40		600	180	460	120		1.1		<.10	<.10		4.2					.19		
	2.80	1543	89	22	50	.2	.50		770	170	590	130		2.1		<.10	<.10		4.2					.19	21	6.8
	.85	1628	50	18	44	.3	.45		470	160	260	100		2.3		<.10	<.10		3.4					.14		
29	.26	0815	70	27	130	.3	.27		330	235	180	20	5.6	6.5		<.10	<.10		5.1						31	7.2
	5.4	0845	237	64	140	.3	1.30		2970	315	2855	235	38.9	1.6		.15	.13		14.9							
	2.8	0905	112	21	120	.3	.72		1200	150	1040	65	17.8	1.2		<.10	<.10		6.2							6.8
	10.89	0922	244	95	120	.3	1.20		3095	315	2925	230	75.0	5.0		.33	.23		61.5							
	2.81	0945	66	38	100	.4	.66		1020	130	945	65	14.8	1.2		<.10	<.10		7.2						16	6.9
	2.81	1000	66		110	.3	.58		645	115	550	30	20.7	1.6		<.10	<.10		10.2							
	3.39	1030	66		120	.3	.59		820	120	715	50	15.8	1.0		.15	<.10		7.6							6.7
33	.38	1445	61	14	22	.2	.38	37	389	299	145	132					<.10			.36			<.10	.15		
	.26	1500	57	16	32	.2	.35	40	361	295	120	145					<.10			.38			<.10	.11	44	6.9
	.72	1515	72	26	30	.2	.39	42	425	306	194	151					<.10			.27			<.10	.15		
	1.38	1530	146	44	34	.2	.66	81	908	321	792	144					.10			.62			<.10	.27	30	6.6
	1.38	1545	134	38	36	.2	.70	110	997	323	825	247					.10			.52			<.10	.24		
	.72	1600	111	44	38	.2	.64	380	722	290	503	221					.13			.35			<.10	.19	28	6.8
	.46	1630	65	34	32	.3	.50	240	394	241	203	139					<.10			.29			<.10	.17		
MEAN			93	30	60	.36	.50	540	834	202	627	102	26.9	2.2	<.10	*.13	*.11	10.3	15.9	.84	<.10	*.26	<.10	.22	32	6.9

* Observations less than detectable limit are included in mean as equal to limit.

Table 70. ANALYTICAL RESULTS OF URBAN RUNOFF FROM SUB-BASIN E-2

Storm No.	Q CFS	Sample Time Military	Organics mg/1			Nutrients mg/1		Fecal Coliform	Solids mg/1				Metals mg/1												ALK mg/1 as $CaCO_3$	pH
			COD	TOC	BOD	K-N	Total-P	#/ml	Total	VS	SS	VSS	Al	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
19	20	1605	50	10	9	.8	.32	160	260	55	150	50			0.1			4.4		.42	<.10	.10			40	7.0
	17	1627	59	10	9	.7	.26	83	215	40	130	45			0.1			3.4		.19	<.10	.10				
	8.8	1654	53	13	8	.7	.22	80	195	45	75	35			0.1			2.8		1.28	<.10	.26			46	7.2
20	14	0335	238			2.4	.32	64	445	205	70	20			0.1			.7		.55	<.10	.36				
	18	0525	142	48		1.2	.30	520			65	5			0.1			.7		.28	<.10	.15				7.0
	30	0700	260	63		1.0	.51	460	365	170	145	50			0.1			2.4		.47	<.10	.68				
	35	0730	464					100			455	145			0.1			13.4		1.07	<.10	1.[illegible]9			45	7.0
	44	0810	204			.8	.97	350	575	195	500	135			0.1			21.6		.63	<.10	.88				
	28	0839	61	40				710			200	30			0.1			4.8		.23	<.10	.38				6.7
	18	0750	40			.6	.24	64	205	85	110	20			0.1			5.2		.14	<.10	.18				
	20	1045	63								125	20			0.1			3.7		.17	<.10	.33				7.0
25	45	1443	136	41	46	.1	.58		1090	150	1000	80		1.6		.12	.12		6.4					.45	20	6.8
	4.6	1500	51	13	44	.2	.46		750	90	430	50		2.2		.12	<.10		4.4					.27		
	45	1518	120		52	.2	.53		1050	120	920	50		2.5		.14	<.10		7.0					.35		6.9
	45	1537	106	14	50	.2	.48		1020	90	950			1.8		.17	<.10		6.2					.33		
	67	1555	85		54	.2	.44		710	80	630	40		1.9		<.10	.11		5.4					.28	24	6.7
	14	1633	35	23	52	.3	.32		290	70	130			4.4		<.10	<.10		4.0					.14		
29	13	0825	82	26	130	.3	.17		140		30		1.6	27.3		<.10	<.10		8.8						52	7.1
	207	0850	198		130	.2	1.40		3190	330	3100	310	43.7	2.5		.34	.21		24.0							
	109	0910	116		130	.2	.77		1450	180	1290	120	23.8	2.0		.11	.15		12.9							7.2
	146	0930	155		130	.2	.85		1960	190	1780	110	29.2	2.3		.27	.14		23.5							
	127	0950	89		110	.2	.70		1390	230	1370	80	22.8	1.3		.15	<.10		9.5						17	7.2
	127	1005	116		140	.2	.48		790	110	760	40	15.7	2.0		.17	<.10		15.4							
	109	1035	89		130	.2	.66		1510	150	1541	70	21.6	1.5		<.10	.11		10.9							
33	28	1450	100	37	34	.2	.39	43	558	265	340	159					.16			.41			<.10	.34		7.1
	25	1505	108	35	42	.3	.36	130	546	160	300	70					.16			.43			<.10	.30	44	6.9
	32	1520	180	45	96	.2	.54	92	662	191	397	92					.17			.61			<.10	.33		
	44	1535	242	62	94	.2	.79	95	1153	235	922	136					.15			.81			<.10	.45	40	6.6
	44	1550	169	32	38	.2	.85	71	1009	241	778	123					.16			.60			<.10	.39		
	44	1605	127	38	42	.2	.64	67	774	181	530	83					.15			.61			<.10	.32	32	6.8
	32	1635	115	28	34	.3	.49	63	641	205	359	81					.13			.47			<.10	.33		
MEAN			130	32	69	.44	.53	185	849	156	638	80	22.6	4.1	.10	.15	.13*	5.7	10.6	.49	<.10	.13	<.10	.32	36	6.9

* Observations less than the detectable limit are included in the mean as equal to the limit.

Table 71. ANALYTICAL RESULTS OF URBAN RUNOFF FROM SUB-BASIN N-2

Storm No.	Q CFS	Sample Time Military	Organics mg/1			Nutrients mg/1		Fecal Coliform	Solids mg/1				Metals mg/1												ALK mg/1 as $CaCO_3$	pH
			COD	TOC	BOD	K-N	Total-P	#/ml	Total	VS	SS	VSS	Al	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
19	8.5	1605	50	76	3	2.6	.99	14	210	60	45	20			<.10			1.2		.16	<.10	<.10			30	7.0
	.38	1627	48	15	3	2.4	.87	23	200	55	35	5			<.10			.8		.17	<.10	<.10				
	.38	1655	42	15	2	2.5	.84	32	235	55	25	5			<.10			.7		.15	<.10	<.10			38	7.0
20	1.8	0335	184	82		1.5	.61	17	375	145	25	25			<.10			1.4		.48	<.10	.10			64	6.8
	1.8	0525	137	61		.8	.52	10			135	55			<.10			2.2		.32	<.10	.14				
	10.1	0700	180	53		.8	.84	180	895	150	350	110			<.10			5.7		.54	<.10	.26				6.9
	17	0730	498	130				200			1530	250			<.10			29.0		.64	<.10	1.25				
	7.1	0810	137	20		.4	.63	160	395	95	315	55			<.10			5.5		2.25	<.10	.54			21	6.6
	1.8	0840	72	26				100			100	60			<.10			2.6		.29	<.10	.58				
	1.6	0950	59	20		.8	.36	21	160	60	35	30			<.10			1.0		.22	<.10	<.10				6.8
	3.1	1045	124	28							145	65			<.10			3.2		.34	<.10	.31				
25	18	1443	82	35	56	.1	.50		1590	220	1370	110		1.1		.14	.12		8.2					.30	16	6.4
	18	1500	50	22	52	.2	.30		830	180	600	70		1.2		.19	<.10		4.4					.19		
	29	1518	132	66	56	.1	1.00		5080	490	5180	470		1.4		.31	.13		14.7					.47		6.4
	18	1537	97	21	52	.1	.42		1160	50	1090	80		1.3		.16	<.10		6.4					.26		
	23	1555	66	32	52	.1	.51		1360	10	1300	120		.9		.13	<.10		6.6					.19	14	6.7
	6.1	1633	112	12	50	.3	.41		380		360	30		1.8		.14	<.10		3.4					.12		
29	4.0	0825	123	50	220	.6	.76		790	90	470	20	12.1	5.4		<.10	.15		10.2						41	7.2
	105.0	0850	146	28	210	.2	.96		2350	140	2610	170	37.3	1.6		.17	.13		18.6							
	14.0	0910	50	20	200	.2	.44		800	60	760	40	15.7	1.0		<.10	<.10		8.1							6.9
	84.0	0930	104	14	180	.2	.90		2480	160	2550	180	36.7	1.8		.22	<.10		17.5							
	52	0950	42	10	190	.2	.46		910	30	870	50	17.7	1.1		0.18	<.10		10.2						13	7.0
	44	1005	46	14	190	.2	.44		910	20	89	70	16.9	.9		.18	<.10		10.2							
	44	1040	38	10	180	.2	.46		970	10	870	40	17.4	.7		<.10	<.10		9.7							6.9
33	4.0	1450	69	25	34	.2	.39	9	455	196	249	132					.12			.34			<.10	.26		
	2.9	1505	69	18	34	.3	.45	12	485	215	282	110					.11			.26			<.10	.28	40	6.9
	6.1	1520	54	16	36	.2	.42	14	420	212	225	115					.13			.46			<.10	.25		
	15	1535	115	18	38	.2	.71	15	841	237	610	152					.17			.64			<.10	.38	46	7.0
	14	1550	96	30	14	.2	.67	18	1010	265	848	19.					.13			.77			<.10	.34		
	14	1605	58	30	28	.2	.50	28	605	97	538	146					.15			.68			<.10	.28	24	6.6
	4	1635	108	16	32	.2	.42	13	484	167	307	114					.15			.52			<.10	.22		
MEAN			102	30	83	.57	.59	50	977	133	770	99	21.9	1.6	<.10	*.16	*.12	4.8	9.9	.51	<.10	*.32	<.10	.27	32	6.8

* Observations less than detectable limit are included in the mean as equal to the limit.

Table 72. ANALYTICAL RESULTS OF URBAN RUNOFF FROM SUB-BASIN W-1

Storm No.	Q CFS	Sample Time Military	Organics mg/l			Nutrients mg/l		Fecal Coliform	Solids mg/l				Metals mg/l												ALK mg/l as $CaCO_3$	pH
			COD	TOC	BOD	K-N	Total-P	#/ml	Total	VS	SS	VSS	Al	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
19	5.5	1617	55	24	11	.4	.33	300	440	70	270	55			<.10			8.8		.97	<.10	<.10			56	7.4
	3.8	1637	43	22	10	.4	.22	250	320	65	155	25			<.10			4.9		3.67	<.10	<.10				
	1.8	1710	35	18	10	.4	.19	280	275	45	85	20			<.10			3.3		2.02	<.10	<.10			60	7.3
20	3.8	0400	230	60		1.0	.64	590	455	195	160	70			<.10			9.6		.9	<.10	.43				
	1.2	0540	87	50		.5	.12	70			35	30			<.10			1.1		.16	<.10	.11			116	7.3
	3.8	0710	176	52		.5	.49	330	520	185	330	95			<.10			17.1		1.01	<.10	.66				
	.29	0745	133	48				290			310	85			<.10			14.5		1.05	<.10	.48				6.7
	23	0823	80	26		.4	.52	510	445	120	295	60			<.10			17.0		.96	<.10	.44				
	6.0	0855	74	30				480			350	75			<.10			18.2		.79	<.10	.22				6.9
	2.4	1005	49	16		.4	.27	550	295	105	110	55			<.10			5.0		.30	<.10	<.10				
	3.8	1100	43	17							95	30			<.10			3.1		.17	<.10	.19				7.1
25	38	1425	124	65	52	.2	.48		800	70	740	140		2.5		.10	<.10		5.4					.15	26	6.7
	138	1440	82	32	46	.2	.31		450	50	340	30		2.4		<.10	<.10		5.0					<.10		
	124	1450	70	22	48	.2	.37		650	50	530	20		2.6		<.10	.10		4.6					.16		6.8
	75	1455	85	31	50	.2	.48		850	170	760	160		1.2		<.10	<.10		6.0					.19		
	32	1510	91	35	48	.2	.49		910	140	750	90		1.6		<.10	<.10		5.8					.21	29	6.9
	32	1525	87	27	52	.2	.57		1340	200	1150	150		1.6		.13	<.10		7.6					.27		
	101	1540	87	24	44	.2	.44		840	140	710	40		1.1		.11	.11		4.0					.24	21	7.0
	167	1555	139	42	46	.2	.76		1690	190	1720	160		1.7		.14	<.10		6.4					.29		
	188	1610	194	26	52	.2	1.10		2810	280	2670	210		1.4		.14	<.10		9.2					.45		6.6
	45	1625	170	63	50	.3	.80		1680	100	1820	190		2.1		.12	<.10		7.2					.35		
	35	1640	127	56	50	.3	.78		1310	90	1400	210		1.9		.38	.12		7.0					.32	18	6.5
	20	1655	119	48	52	.3	.62		1200	200	940	60		2.5		<.10	.11		7.2					.25		
29	51	0835	58		150	.3	.32		430	100	280	40	6.8	4.8		.10	<.10		8.0						51	7.4
	341	0900	74		130	.3	.42		460	70	350	60	9.9	1.9		<.10	<.10		6.4							
	167	0920	132	38	140	.2	.83		1790	180	1680	140	27.1	1.7		.17	.11		13.2							6.8
	167	0940	109	34	140	.3	.79		1030	120	920	50	18.6	1.2		<.10	<.10		9.4							
	209	1000	116	40	120	.3	.82		1350	70	1330	90	22.8	1.0		.17	<.10		12.2						15	6.3
	190	1020	101	41	120	.3	.76		1140	130	1050	120	24.4	1.0		<.10	<.10		9.5							
	297	1050	76	23	140	.3	.58		850	110	700	30	14.2	.9		.11	<.10		7.5							6.8
33	9	1445	42	26	68	.3	.26	31	234	119	25	6					<.10			.21			<.10	.12		
	51	1515	46	42	20	.3	.32	32	279	168	64	52					<.10			.21			<.10	.13	42	7.1
	11	1545	146	58	42	3.6	1.70	27	361	234	106	74					<.10			.11			<.10	.19		
	16	1615	54	12	28	.3	.35	27	295	130	113	58					<.10			.32			<.10	.13	28	6.9
	15	1645	56	16	18	.3	.42	61	373	146	169	151					.11			.17			<.10	.16		
	14	1715	42	34	22	.3	.39	58	322	187	131	152					<.10			.21			<.10	.11	32	7.0
MEAN			95	35	36	.42	.54	242	819	132	629	87	17.7	1.8	<.10	*.13	*.10	9.5	7.5	1.09	<.10	*.27	<.10	*.32	41	7.0

* Observations less than detectable limit are included in the mean as equal to the limit.

Table 73. ANALYTICAL RESULTS OF URBAN RUNOFF FROM SUB-BASIN W-2

Storm No.	Q CFS	Sample Time Military	Organics mg/l			Nutrients mg/l		Fecal Coliform	Solids mg/l				Metals mg/l												ALK mg/l as $CaCO_3$	pH
			COD	TOC	BOD	K-N	Total-P	#/ml	Total	VS	SS	VSS	Al	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Sr	Zn		
19	.49	1610	73	17	9	.4	.29	310	285	50	135	25			<.10			4.4		.19	<.10	<.10			54	7.2
	.54	1632	40	14	9	.4	.25	280	265	50	110	25			<.10			4.2		.18	<.10	<.10				
	.24	1700	33	15	9	.4	.15	270	240	40	60	15			<.10			2.9		1.21	<.10	<.10			64	7.4
20	.62	0350	74	31		.5	.38	800	320	320	35	35			<.10			8.6		.77	<.10	<.10				7.2
	.20	0530	94	41		.6	.35	240			55	40			<.10			11.9		.95	<.10	.28				
	1.9	0705	110	40		.4	.59	910	560	150	345	95			<.10			29.6		1.24	<.10	.61			54	7.1
	5.0	0738	139	34				1000			705	140			<.10			27.4		1.26	<.10	.40				
	3.3	0818	118	38		.4	.80	170	615	105	530	93			<.10			23.8		.86	<.10	.45				7.0
	1.4	0847	72	30				120			265	95			<.10			20.2		.50	<.10	.16				
	.62	1000	59	21		.4	.26	20	225	55	115	55			<.10			5.4		.23	<.10	.25			40	7.3
	.54	1050	35	30							45	35			<.10			2.7		.11	<.10	.19				
25	4.2	1447	210	54	48	.2	.91		2160	150	2175	250		2.5		.32	.11		14.1					.57	51	7.3
	3.8	1505	116	43	48	.2	.41		820	30	800	100		2.9		<.10	<.10		5.8					.22		
	3.3	1523	82	27	40	.2	.38		860	160	660	260		2.1		.10	<.10		5.8					.18		7.1
	31	1542	175	57	54	.2	.96		3930	410	3810	500		1.3		.19	.16		11.4					.41		
	22	1558	178	16	52	.2	.65		1660	260	1640	350		1.5		.11	.16		7.0					.43		
	5.2	1638	105	60	50	.3	.52		760	160	610	280		3.1		.12	<.10		4.8					.20	22	6.9
29	6.5	0830	210	22	190	.4	.4		890	10	790	40	13.5	3.9		.13	<.10		10.4						51	7.3
	24	0855	279	78	200	.3	1.7		2930	240	2870	290	42.2	2.5		.34	.15		21.8							
	15	0915	159	52	200	.3	1.1		1480	120	1760	410	28.0	1.4		.28	.16		16.0							6.8
	25	0935	116	38	200	.2	.8		1490	100	1380	140	23.0	1.0		.19	.11		11.3							
	25	0955	180	48	190	.3	1.1		1630	90	1670	150	24.1	1.3		.12	.15		10.9						18	6.9
	19	1015	100	24	200	.3	.61		800		740	40	13.6	1.3		<.10	<.10		5.8							
	25	1045	81	22	210	.3	.69		940	70	890	40	16.4	1.5		.22	.12		14.3							6.9
33	1.5	1455	35	22	16	.3	.30	31	274	158	35	147				<.10				.22			.12	.15		
	1.3	1510	27	16	14	.3	.28	35	268	118	18	128				.10				.19			.14	.12	46	7.1
	2.3	1525	58	19	28	.3	.38	41	385	149	155	139				<.10				.31			.10	.13		
	3.3	1540	42	18	26	.3	.36	50	360	146	96	89				<.10				.22			<.10	.16	40	7.0
	3.3	1555	42	18	26	.2	.52	84	413	208	157	113				<.10				.30			<.10	.17		
	3.3	1610	58	34	26	.3	.59	95	413	181	159	150				.13				.31			.10	.18	38	7.1
	2.3	1640	46	16	26	.3	.49	56	363	178	106	138				<.10				.34			<.10	.14		
MEAN			101	32	81	.31	.57	265	938	134	739	142	22.9	2.0	<.10	*.15	*.12	12.8	10.7	.52	<.10	*.25	*.11	.23	43	7.1

* Observations less than detectable limit are included in mean as equal to the limit.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-670/2-74-096	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE CHARACTERIZATION AND TREATMENT OF URBAN LAND RUNOFF		5. REPORT DATE December 1974; Issuing Date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Newton V. Colston, Jr.		8. PERFORMING ORGANIZATION REPORT NO
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of North Carolina Water Resources Research Institute 124 Riddick Building, North Carolina State University Raleigh, North Carolina 27607		10. PROGRAM ELEMENT NO. 1BB034/ROAP:2[illegible]-ATB/TASK:014 11. CONTRACT/GRANT NO. 11030 HJP
12. SPONSORING AGENCY NAME AND ADDRESS National Environmental Research Center Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final - 7/71 to 9/73 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Urban land runoff from a 1.67 square-mile urban watershed in Durham, North Carolina, was characterized with respect to annual pollutant yield. Regression equations were developed to relate pollutant strength to hydrograph characteristics. Urban land runoff was found to be a significant source of pollution when compared to the raw municipal waste generated within the study area. On an annual basis, the urban runoff yield of COD was equal to 91 percent of the raw sewage yield, the BOD yield was equal to 67 percent, and the urban runoff suspended solids yield was 20 times that contained in raw municipal wastes for the same area. Downstream water quality was judged to be controlled by urban land runoff 20 percent of the time.

In urban drainage basins, investments in upgrading secondary municipal waste treatment plants without concomitant steps to moderate the adverse effects of urban land runoff are questionable in view of the apparent relative impact of urban land runoff on receiving water quality.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Runoff, *Surface drainage, *Water pollution, Flocculants, Waste treatment, *Water quality, Coagulation, Computers	*Urban runoff, *Storm runoff, *Urban drainage, *Stormflow, *Water pollution sources, *Stormwater characterization, Storm water management model	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 170
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

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